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JUNE 1951

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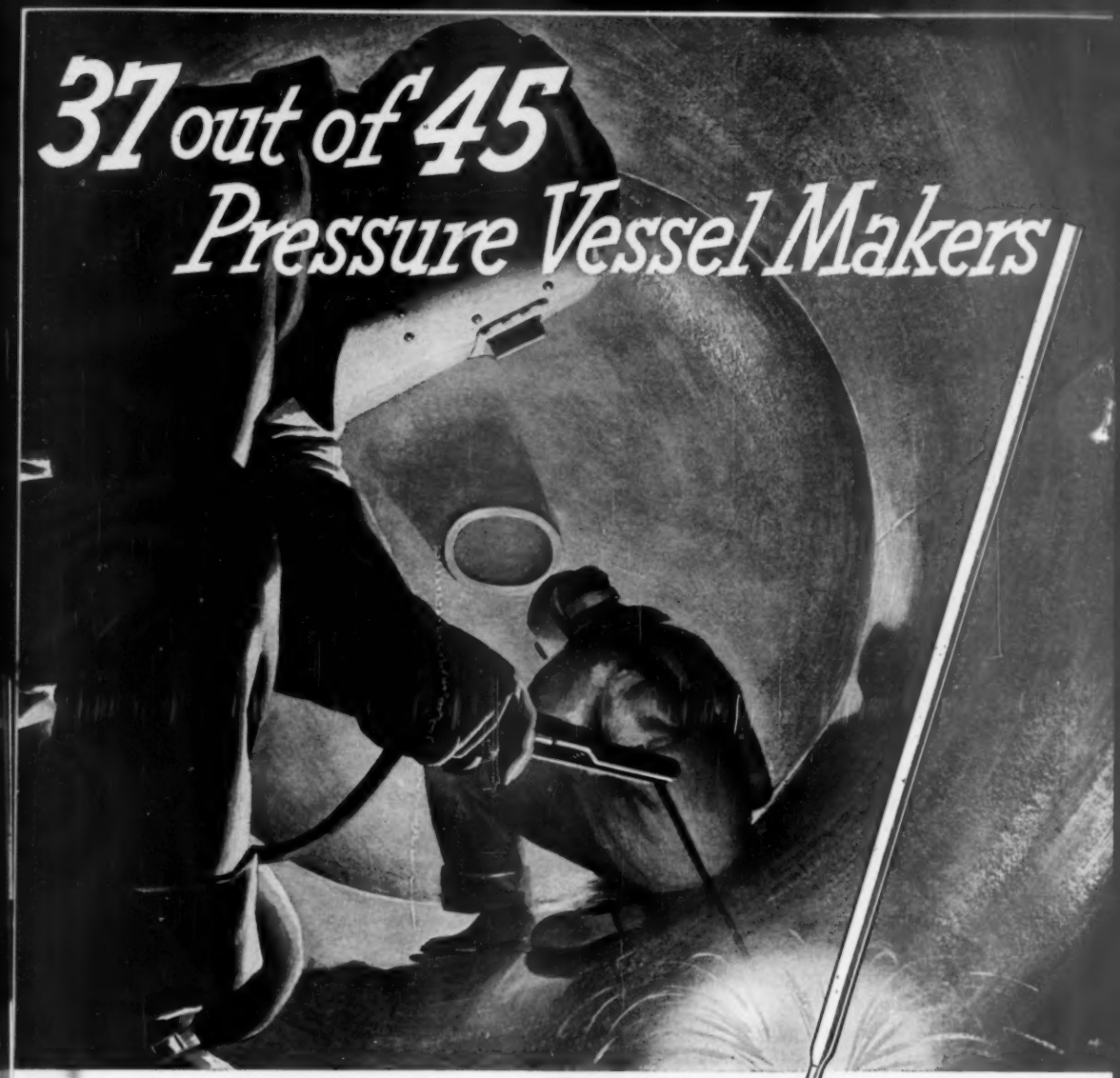

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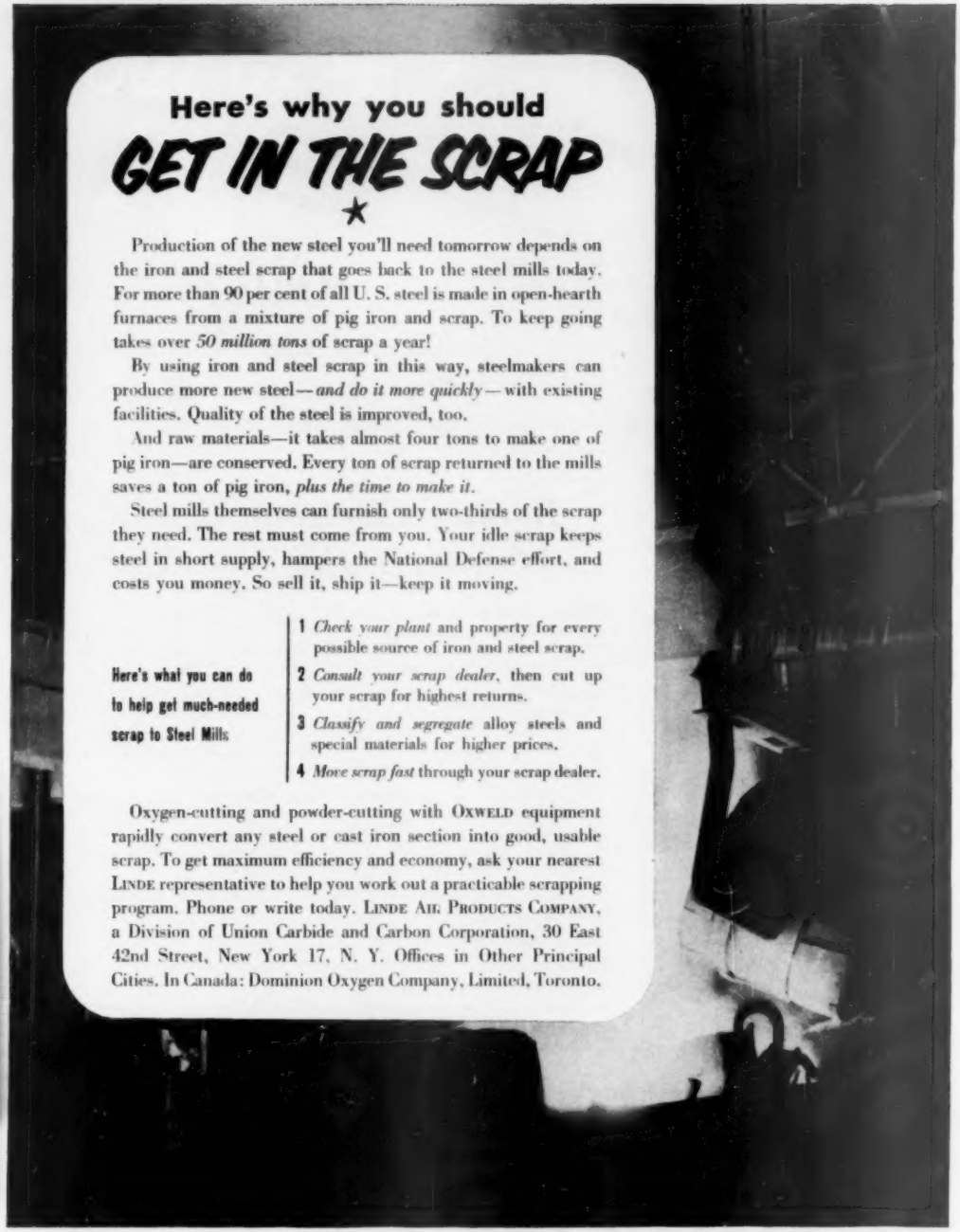

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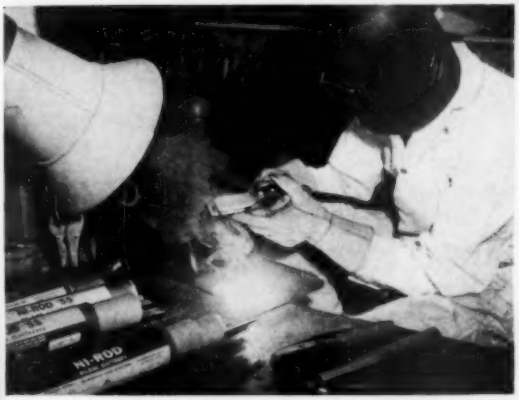

3. Ten minutes, twenty minutes, thirty minutes gone. Now I'm beginning to get the feel. I'll show these birds yet. Stick in there, Ni-Rod. Make me a bead so straight it'll knock 'em for a loop . . .

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The WELDING JOURNAL

volume 30 June 1951 number 6

Welding and Its Effect on the Corrosion Resistance of Stainless Steel

Welded stainless steel failures due to corrosion and methods of correcting causes of such failures

by E. W. Hopper

THIS paper is not intended to present theoretical aspects of intergranular corrosion resulting from welding operations. Neither does it add anything to the great volume of information which has been published on the mechanism for the development of carbides, sigma-phase or ferrites, which may precipitate and cause failure. It is concerned with those stainless failures which are an everyday occurrence in industries where corrosive solutions are handled. It is also concerned with methods for correcting the basic causes for such failures wherever possible.

The problem has assumed a position of greatly increased importance since the beginning of the National Emergency. The austenitic chrome-nickel stainless steels are not available in sufficient quantity to take care of all demands from the Chemical and Process Industries. Therefore, any such material installed should be handled in a manner so that the corrosion resistance is not deleteriously affected, necessitating repair or replacement. Most of the equipment going into the industries mentioned requires some welding in its fabrication. Every attempt should be made to minimize the harmful effect of such welding on the service life of the stainless steel.

STABILIZED STAINLESS STEELS

Although columbium and titanium are both used as additions in stabilizing chrome-nickel austenitic steels against carbide precipitation, titanium has not been seriously considered for use in the corrosion-resistant field. It is lost in electric arc welding and, when used, is normally welded with a columbium stabilized rod. Our own experience in the production of welded stainless tubing has indicated that some of the currently produced titanium stabilized stainless can be satisfactorily welded using a "protected atmosphere" process. The value of columbium as an addition has been well established by many years of service under all types of corrosive conditions.

The benefits of columbium stabilization has been presented by Becket and Franks.[1] The general corrosion resistance of the steel is not improved by the addition of columbium when the material is in the properly annealed condition. In fact, in several cases involving the handling of high concentration sulphuric acid, tests indicated inferior corrosion resistance. However, the columbium stabilized grades have permitted welding without consideration of the time the steel has been in the sensitizing temperature range.

Columbium stabilized austenitic chrome-nickel steels are not obtainable for commercial use. The supply of this strategic metal is not sufficient to take care of critical requirements. Therefore, those industries and plants able to secure any stainless must get by on non-columbium stabilized grades.

SPECIAL LOW-CARBON STAINLESS

The development of very low-carbon austenitic chrome-nickel steels has helped to solve some of the difficulties currently facing industry due to the inability to furnish stabilized grades. The carbon content of these steels has been lowered over the years, until the normal content of types 304 and 316 grades is in the

E. W. Hopper is Chief Chemical Engineer with Crucible Steel Co. of America, Pittsburgh, Pa.

This paper was presented before the Seventh Western Metal Congress held in Oakland, Calif., March 19th to 23rd, 1951.

range of 0.05–0.08%. This figure has not been low enough to prevent weld failure. However, with the advent of the 0.03% max. carbon, the danger of intergranular corrosion as a result of welding has largely disappeared.

The results obtained by Binder, Brown and Franks[2] have indicated that integranular carbide precipitation in the average Type 304 analysis, with carbon under 0.03%, would be insufficient to cause failure from welding. The same results are indicated in the case of Type 316 with 2% molybdenum and 0.03% max. carbon. Curves published in this excellent paper show minimum times required to develop intergranular attack with varying carbon and nitrogen contents and different chrome-nickel ratios, also with molybdenum present. The added effect of nitrogen in causing intergranular attack is also pointed out. Corrosion tests run on welded samples confirm the evidence of freedom from intergranular corrosion in these low-carbon grades.

GENERAL CONDITION OF STAINLESS IN INDUSTRY

It is quite likely that if all the austenitic chrome-nickel stainless steel in use were of the columbium stabilized or very low-carbon grades, that very few cases of intergranular corrosion would develop from welding operations. If that were so, there would be little reason for much of the work I am required to follow, and more of my time might be devoted to applications where general corrosion resistance is of prime importance.

However, most of the austenitic stainless now being consumed by the Chemical and Process Industries does not fall into the above categories. Neither does the great bulk of stainless equipment installed in the plants consist of the stabilized very low-carbon grades. New equipment is being fabricated and old repaired or changed. This work requires welding, and the stainless is susceptible to carbide precipitation and intergranular attack. Fortunately, the large percentage of welded vessels, tanks, tubing, etc., does not develop trouble. However, the small percentage that does fail as a result of intergranular attack merits serious consideration.

CARBIDE PRECIPITATION AND INTERGRANULAR ATTACK

When such failures occur they are generally adjacent to the weld and not in the weld metal. The surface, frequently 1/8 to 3/8 in. from the weld, becomes rough and pitted, sometimes to the point of complete penetration. The attacked metal may be rough and individual grains can sometimes be rubbed away. Occasionally the weld metal may be similarly attacked, generally when heavy plate is welded and multiple beads are required.

Figure 1 is a photomicrograph at 500× of a section of Type 316 stainless, showing very heavy carbide precipitation at the grain boundaries. Figure 2 is a

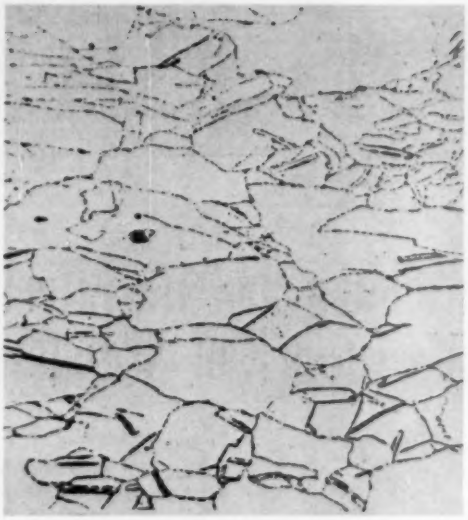

Fig. 1 Oxalic-acid etch showing carbide precipitation at grain boundaries. 500 ×

photomicrograph at 500× showing a section of the same sample pictured in Fig. 1. It illustrates the intergranular attack on the stainless which caused a weld cover of a process vessel to fail. The intergranular attack had caused the affected area to crack through. The affected stainless could be crushed into a powder by hand pressure. The corrosive medium in this case was condensed acetic-acid vapors. The cover was corroded only in the area surrounding the welds and the affected zone was about 6 in. long. The location was close to where a stainless angle had been welded to the cover as a stiffener. The chemical analysis of the stain-

Fig. 2 Oxalic-acid etch showing failure due to intergranular attack. 100 ×

less analyzed as follows: C 0.13%, Mn 1.84, P 0.020, S 0.018, Si 0.32, Ni 14.35, Cr 17.41 and Mo 2.25.

The stainless is Type 316 with carbon and nickel both above the upper limits set by the type specification. The precipitation of the carbides was undoubtedly aggravated by the high carbon content and probably further affected by the high nickel.

However, the steel in spite of the high carbon content was sufficiently corrosion-resistant away from the heat-affected zone to give satisfactory service. It can therefore probably be assumed that the plate material, about 1/4 in. thick, was originally in the properly annealed condition.

ANNEALING TO CORRECT RESULTS OF SENSITIZING

When carbides precipitate as a result of welding or some other form of heat, the condition can only be remedied by redissolving the carbides and keeping them in solid solution. This can only be secured commercially through full annealing, preferably at a temperature of 1900–2100° F. for a period of time depending on the thickness of material, followed by fast cooling. For light gage stainless, atmospheric cooling or an air blast may be sufficient. For heavy plate or bars, water quenching or spraying is required. At any rate, the entire vessel or part should be down to complete black in a period preferably under two minutes.

An annealing treatment will not correct a condition as observed in the above-mentioned cover, where the vessel had been in service and failed due to intergranular attack. In such a case, repair of one means or another is necessary. Rewelding cannot be satisfactorily performed in such an attacked area. The porous and crumbling stainless is best cut out away from the heat-affected zone and a new section welded in.

USE OF COLUMBIUM STABILIZED WELDING ROD TO PREVENT CARBIDE PRECIPITATION

On recent surveys through the Eastern United States, I had an excellent opportunity to see weld failures and the attempted repairs in industrial plants where we held "Welding Clinics." The plant maintenance departments were repairing, connecting or installing stainless equipment of various kinds. In a number of plants, the Engineering, Maintenance and Purchasing Departments had been completely sold on the use of columbium stabilized welding rod for the elimination of weld failures. In some cases "up grading" had been recommended and was being followed. This referred to the use of a higher alloy rod, generally 310 + Cb, for all-purpose welding, including that of Type 316 and, in one case, "Hastelloy C." The results obtained on the Type 316 and Hastelloy welded with 310 + Cb rod had not proved satisfactory. The weld metal had eaten out and the resulting failures had caused it to be brought to our attention.

It is sufficient to say that there is no advantage to be gained in the use of either columbium stabilized or very low-carbon welding rod for the elimination of precipitated carbides in the welding of normal carbon content stainless steel. The weld metal is incapable of correcting the condition which develops in the heat-affected parent metal separated from the weld metal.

PROTECTED ATMOSPHERE VERSUS COATED ROD WELDING

In the course of the "Clinics" we found a number of plants where "protected atmosphere" or "inert-gas atmosphere" welding had been substituted completely for electric arc in the welding of austenitic stainless steels. This replacement had also been made in order to eliminate precipitated carbides and weld failures. The "inert-gas atmosphere" welding is ideal for relatively light gages, where tight assembly is possible and no filler metal is required. In many of the cases examined these conditions did not exist. Some very bad failures had developed in large process lines where stainless up to 3/16 in. thick with poor fit had been field erected. The welding operation could have been finished in much less time using electric arc welding with a coated rod.

Our welded stainless tubing is all protected atmosphere welded. There, the conditions are ideal for this type operation. The stainless is continuously rolled into a tube with the two edges tightly butted together, automatically welded, with inert gas inside and outside the tube.

Normally, on gages heavier than 16, coated rod welding will be faster than the inert-gas type. Therefore, the time at temperature and the sensitizing effect may be greater.

WATER COOLING WELDS

If properly annealed stainless steel, with normal carbon content, is welded in such a manner that the time in the sensitizing temperature range, that is from 1500 to 900° F., is less than two minutes, no serious loss in corrosion resistance in the weld zone is likely to result. This condition of limited time at temperature can be secured by use of rapid welding technique, followed by fast cooling. On very light gages, atmospheric cooling or an air blast played on the surface may be sufficient to control the precipitation of carbides to such an extent that damage by intergranular attack will not occur.

In many cases copper chill bars are used to back up the weld and remove heat from the area more rapidly. Such cooling is frequently ineffective due to imperfect contact with the metal. Furthermore, the use of chill bars is likely to be difficult where field welding is required.

We have for a considerable period of time emphasized the desirability of employing rapid welding and cooling for all grades of austenitic chrome-nickel stain-

less. The most effective cooling medium is water. It can either be applied as a very small stream or spray, or by swabbing the surface with a wet sponge or piece of waste. Where the weld is followed by a fine stream of water at a short distance, say 6 to 8 in., continuous welding can be carried on. Otherwise, no longer than one minute of uninterrupted welding from the time the arc is struck should be permitted. The weld area should then be water swabbed immediately. In normal welding practice, a coated rod is used up in less than one minute and is therefore a satisfactory method for judging time. Water cooling of protected atmosphere welds is just as necessary as with coated rod.

TYPICAL CASE—WATER-COOLED VERSUS NORMAL PRACTICE

The value of such treatments as outlined above is shown by an installation which we are still following. Heat exchanger coils were fabricated from welded Type 316 stainless tubing and return bends. The tubing was $2^1/_4$ in. O.D. by 11 gage and the return bends were formed from similar tubing. The heat exchangers are used to cool acid solutions with a pH of 2.0 to 4.5, acidified with sulphuric, acetic, hydrochloric or nitric acid. Temperatures range up to the boiling point.

The tubing and return bends were originally butt welded together to form the coils. Type 316 coated rod was used for the welding operation. After five days of operation, the coils had perforated and were leaking. The units were shut down, cleaned out and the perforations closed with weld deposits. When returned to service, the weld areas failed almost immediately. The units were again shut down, the coils removed and the return bends cut out. Examination of the tubing and return bends showed the attack to have occurred adjacent to the circumferential butt welds. There appeared to be no visible attack on the tubing or return bends. The weld made in forming the welded tubing showed no evidence of corrosion.

New return bends were rewelded in place a second time using the inert-gas welding process. When placed in service again, failure occurred in three days adjacent to the weld zone.

Samples of the welded sections were submitted to our laboratory for a chemical and microscopic examination. The chemistry on the first failed samples follow:

	C	*Mn*	*P*	*S*	*Si*	*Ni*	*Cr*	*Mo*
Return bends	0.10	1.32	0.030	0.020	0.56	13.71	17.89	2.22
Straight sections	0.09	1.76	0.029	0.019	0.39	13.07	18.48	2.43
Weld deposit	0.09	1.74	0.029	0.020	0.35	13.51	19.22	2.30

A typical circumferential weld section at 1.5 × is shown in Fig. 3. It shows the heavy weld metal cross section. Just adjacent to the weld metal and in the base metal there is a large void apparently due to corrosive attack. Figure 4, taken at 100×, shows a void and the intergranular attack. Figure 5, also at 100 ×, shows the precipitated carbides at the grain boundaries and an area of weld metal. Microscopic examination of the second set of samples also showed carbide precipitation and intergranular attack.

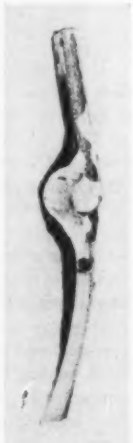

Fig. 3 Section through weld bead. 1.5 ×

Fig. 4 Oxalic-acid etch intergranular corrosion in heat-affected zone. 100 ×

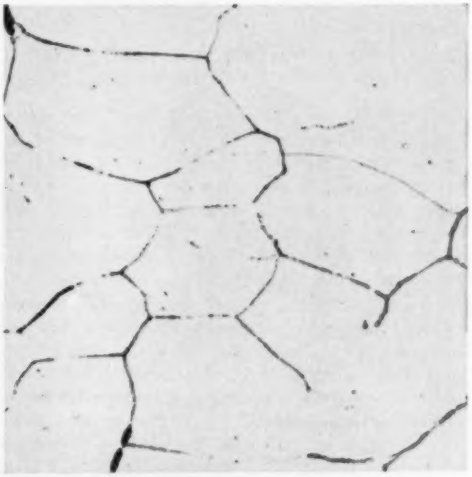

Fig. 5 Oxalic-acid etch precipitated carbides at grain boundaries in heat-affected zone. 100 ×

It is rather hard to convince the plant engineer that stainless steel might perform on this application. He finally agreed to have an outside fabricator make the installation. Another set of return bends was made up, degreased, full annealed at 2000–2100° F., water quenched, pickled and welded into place using Type 316 titania-coated A.C.-D.C. rod. Welding was limited to 1 min. maximum, followed by water swabbing. These coils were placed in operation in September 1950, and now have over five months' service. No leaks have been observed so far.

The tubing in all cases was the same. The return bends are, so far as we know, made up from the same stock used in making the original lot. The improved results can, I believe, be safely attributed to the limited time in the critical sensitizing range as the operating conditions are undoubtedly the same.

CONCLUSION

The cases noted here are, of course, only isolated failures out of many which have occurred. I looked over two lots of samples in the laboratory recently where intergranular corrosion at the weld area had caused failure. One of these is tubing handling paper mill white water with a small concentration of chlorine present. Types 304 and 316, containing in each case 0.09% carbon, had been used. The welds in the Type 304 had failed due to intergranular attack; the Type 316 had not perforated but showed serious penetration adjacent to the weld. It would have been a simple matter to weld rapidly and water cool for greatly improved corrosion resistance in the weld area. The other samples were cut from the shell of a large tubular heat exchanger, supposedly fabricated from Type 304. The corroding agent was acetic acid. Failure occurred through cracking in the weld area. The affected areas appear to be intergranularly corroded. Here again it would have been a simple matter to swab water on the weld.

It is very probable that the failure which occurred on the stainless cover, subject to acetic acid condensate, could have been prevented by packing water soaked waste around the weld area or by welding and water spraying.

The use of water cooling is certainly not new or novel. We have recommended its use where tanks or coils might be filled with water during the welding operation, in order to prevent not only carbide precipitation, but discoloration, warping and reduction of iron and carbon migration where carbon steel is welded to the stainless.

Our recent "Welding Clinics," held at industrial plants and fabricating shops throughout the country, have indicated an astonishing lack of appreciation of the basic causes of these failures. There have also been very few ideas as to methods which might be used for correction.

Such procedure as outlined is simple, easily applied and adds little to the cost of the normal welding operation. It is available for field or shop fabrication. No special rods are required. Above all, it is directly applicable to much of the stainless now in service or being manufactured which is subject to carbide precipitation and intergranular corrosion failures. Any procedures which can help to reduce these controllable failures and save the unnecessary waste of stainless steel should be employed.

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Design and Fabrication of Steam Piping

Selection of material, stress calculations and welding procedures in the design and welding of high temperature steam piping

by A. W. Rankin and R. W. Clark

INTRODUCTION

ONE of the most distinctive features of the engineering of both public-utility land power stations and marine propulsion equipment has been the steady increase in the steam turbine operating temperatures which has occurred over the last fifty years as is illustrated in Fig. 1 for land power stations. There are undoubtedly many requirements in marine engineering which result in design specifications for propulsion units which differ in major particulars from their counterparts in land power units, but this drive to the higher operating temperatures is common to both fields. Starting at 500° F. in 1905, and increasing at the rate of about 12° F. per year, land turbines have reached and are operating at the 1000° and 1050° F. temperature levels, with commitments already made for 1100° F. The first major land turbine for 1000° F. operation went into operation at that temperature in 1946; the step to the 1050° F. level was made in late 1948, and already in production design are two large 1100° F. units for installation in 1952. Marine engineering has already reached the 1000° F. level in turbine operation,[1] and there seems no reason to doubt that further advances will be made after the 1000° F. level is adequately consolidated.

The basic engineering factor which makes practicable the higher operating temperatures, and which dictates when further advances are possible, is the development of a steel which will operate reliably at the desired temperature level. In the experience of the authors, the development of a satisfactory high-temperature steel which can be cast and forged in large sizes transcends all other engineering factors in importance, and the lack of a satisfactory steel can reduce engineering calculations to a level of mere academic interest.

Considering the complexity of the science of metals, metallurgists have done a magnificent job in ferreting out sufficient basic metallurgical laws to enable them to develop the steels which permit the engineers to build those structures, as, for instance, high-temperature turbines, which characterize our way of life, and also to build the structures, such as the still-hotter jet engines, which are necessary to defend our way of life. After somewhat intimate contact with design and manufacturing problems in the production of large industrial equipment, the authors are very cognizant of the degree to which our national economy and defense rest upon the efforts of our metallurgists, and in particular upon the degree to which we must allocate sufficient financial assistance and personnel to such efforts.

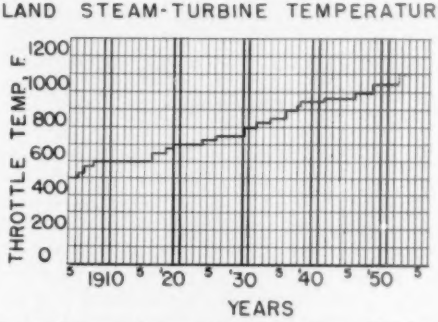

Fig. 1 Increase in operating temperatures of land steam turbines during last forty-five years

Based on the authors' experience in turbine design, advances in the engineering of the high-temperature components of our economy and defense can be made only with the closest cooperation between engineers and metallurgists. A particular example where such cooperation is necessary is in high-pressure high-temperature piping. This paper is planned to discuss some of the aspects of the design and welding of such piping, and the selection of these two phases itself illustrates the close coupling between engineering and metallurgy.

With respect to design, this paper will discuss some of the general features of material selection and stress calculation, while, in regards to welding, several of the important factors which control the delivery of a sound weld will be discussed. In consideration of the present general use of welded joints in piping instead of flanged

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and bolted connections, it does not seem necessary to discuss at this time the general advantages of a welded joint such as reduction in weight, lower cost and freedom from leakage.

DESIGN OF HIGH-TEMPERATURE HIGH-PRESSURE PIPING

Selection of Piping Steel

Concomitant with the increase in turbine operating temperature has been an increase in the alloy content of the steels used for piping at these high temperature levels. These higher alloy contents are needed primarily to obtain the necessary long-time high-temperature physical properties; in particular, to obtain adequate creep and rupture strength. Figure 2 illustrates the phenomena of creep; it shows how a steel when operating at high temperature will gradually elongate under tensile stress. This particular steel is a quenched and tempered nickel-chrome-molybdenum steel on which tests were carried out to 100,000 hr., which is 11.5 yr.[2] The maximum plastic strain shown of 0.40% corresponds to an elongation of 4 mils per inch. The

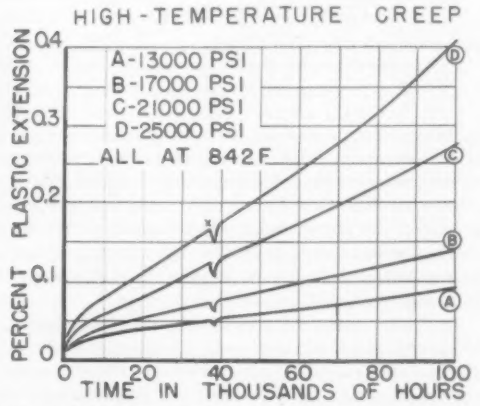


Fig. 2 High-temperature creep of a quenched and tempered nickel-chrome-moly steel at 842° F. At points marked x, loads were dropped to 1000 psi. during movement of furnace to a different building

present codes on piping permit a plastic extension at 100,000 hr. of 1%, but these particular curves were obtained for turbine construction in which it is sometimes necessary on rotating equipment with close clearances to maintain smaller creep than can be accepted on piping. In the authors' opinion, creep on piping is somewhat overemphasized as a plastic strain of greater than 1% could easily be accepted on many installations. In fact, there is some justification in the question as to why creep strength is considered as an important factor in published safety codes, as dimensional stability does not often have any major effect on the degree of safety.

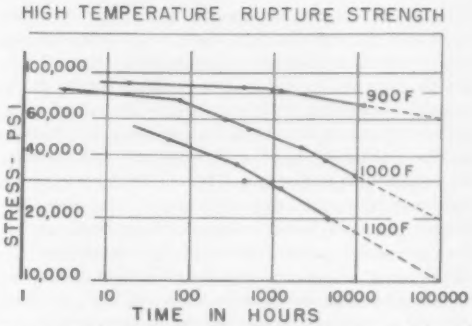


Fig. 3 High-temperature rupture of a quenched and tempered moly-vanadium alloy

Figure 3 illustrates the phenomena of long-time rupture; it shows how a steel when operating at high temperature will suddenly rupture after long periods of operation at stresses considerably less than could be permitted if only room temperature operation were necessary. This particular steel is a normalized and tempered molybdenum-vanadium alloy used for rotor forgings. These tests were carried out for 11,000 hr. maximum (which is $1^1/_4$ yr.), and the 100,000-hr. rupture strength is obtained by extrapolation. To the authors' knowledge, no 100,000-hr. rupture tests have been conducted; it is the practice of the authors' company to carry out these tests for approximately 10,000 hr. on steels in production use, and accept the extrapolation of another cycle of the log paper. It is obvious, of course, that a 100,000-hr. test is difficult to obtain as it would tie up a testing furnace for more than ten years. The information presented in Fig. 3 illustrates the importance of adequate consideration of the long-time rupture strength, and of the degree to which it may affect reliability and safety of personnel.

The design practice of the authors' company is to ignore creep strength where the plastic strain cannot affect operation, but to maintain a safety factor of at least 2 on the 100,000-hr. rupture strength, although this factor may be overconservative as some piping codes accept somewhat lower factors. It should be noted, however, that the stress calculations specified in piping codes frequently include hidden safety factors whose influence should be studied when considering design practices and experience on high-temperature piping alloys.[3, 4]

Creep in the steels used for power plant construction first received engineering consideration in the late 1920's when turbine temperatures exceeded 750° F. The phenomena of long-time rupture, however—although it had occurred in some creep tests at an earlier date—did not receive much engineering publicity until the late 1930's. With this discovery of creep at turbine operating temperatures, development work was initiated to discover alloys and heat treatments which would increase the creep resistance, and with the discovery of long-time rupture these developments were

expanded to consider rupture strength. The principal result was the molybdenum steels, and their variants such as the molybdenum-vanadium steels and others, and these relatively simple alloys sufficed for the more common operating temperatures. Chromium was added to obtain both oxidization resistance and graphitization resistance, and the chrome-moly and chrome-moly-vanadium steels, and other steels developed for particular pipe and tube applications, were then obtained. For still better creep and rupture strengths, the austenitic stainless steels of the 18% chromium–8% nickel family, either columbium-stabilized or otherwise, are available, but these steels are so high in cost that they cannot always be justified on an economic basis. Further development work has resulted in the introduction of the less common alloying elements, such as cobalt, boron, etc., but these have not yet been used to any extent in steam piping.

On Fig. 4 are plotted the 10^{-7} per hour (1% per 100,000 hr.) creep strengths of some of the various ferritic alloys which the authors' company is using for steam piping between the emergency stop valve and the turbine shell. These are from published tests and from tests made in this company's laboratories, and are average values taken from several tests. Test data on both creep and rupture strength sometimes scatter considerably not only from heat to heat but sometimes even within a single heat, and it is not always possible to obtain close correspondence in the results taken from several laboratories. This is a phenomena which, although as yet unexplainable and definitely annoying, should be considered whenever considerable test data are not available. It should be noted, incidentally, that the authors' company generally uses piping in the normalized and tempered condition in order to obtain the optimum values of creep and rupture strength.

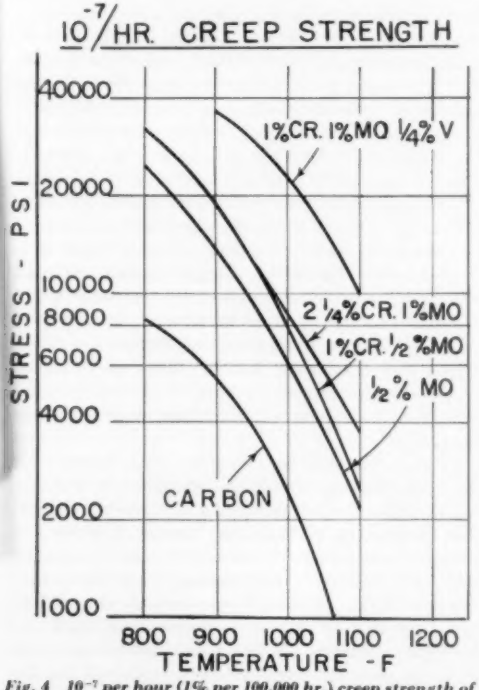


Fig. 4 10^{-7} per hour (1% per 100,000 hr.) creep strength of some particular ferritic piping steels; average values

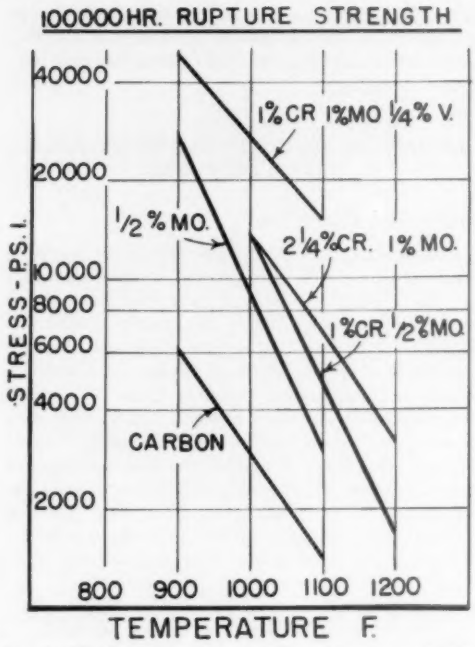


Fig. 5 100,000-hr. rupture strength of some particular ferritic piping steels; average values

In Fig. 5 are shown the 100,000-hr. rupture strengths of the ferritic alloys whose creep strengths are shown in Fig. 4. The range in high-temperature strength from the simple carbon steels to the more complex alloys as shown in Figs. 4 and 5 illustrates vividly the primary reason why the higher turbine operating temperatures require more highly alloyed steels as it can be seen here how the high-temperature strength increases with proper addition of the alloying elements. It should be understood from general experience, however, that better high-temperature strength cannot be obtained without some sacrifice in room-temperature properties, and the practice of the authors' company is to accept a reduction in room-temperature properties if such reduction is concomitant with better high-temperature properties. Room-temperature properties should be such as to give adequate processing characteristics, but an overabundance of room-temperature properties, as for instance ductility, is a luxury that cannot always be permitted in our present shortage of steel and mining man power.

STEELS FOR TURBINE STEAM LEADS

750F AND LOWER	- CARBON STEEL
751F TO 825F	- ½ % MOLY
826F TO 950F	- 1%CHROME ½% MOLY
951F TO 1000F	- 1%CHROME 1%MOLY ¼% VAN.
	OR 2¼% CHROME 1% MOLY
1001 TO 1050F	- AUSTENITIC
	OR 1%CHROME 1%MOLY ¼% VAN
	OR 2¼%CHROME 1% MOLY
ABOVE 1050F	- AUSTENITIC

Fig. 6 Design practice of the authors' company with respect to steam leads for large turbines

This table is not intended as a recommended practice for all manufacturers and all applications, but is intended only to illustrate the practice of a particular engineering organization. There are no hard and fast rules specifying the maximum operating temperatures of various steels; the arbitrary limits shown in the above table are set primarily to obtain consistent designs and to ease the procurement and manufacturing problems of this particular organization, and, in particular, are not intended to imply that the above steels would not be satisfactory at higher operating temperatures if the stresses are commensurate with the material strength at the desired temperature.

In Fig. 6 is shown the practice of the authors' company with respect to the steels used for steam piping between the emergency stop valve and the turbine shell for large turbines. Carbon steel is used only up to 750° F., above this temperature the moly steels are used to get the necessary creep and rupture strength. At 826° F., the chromium-containing steels are introduced in order to get adequate graphitization resistance. Between 951° and 1000° F., either the 2¼% chrome–1% moly steel or a 1% chrome–1% moly–¼% vanadium steel is employed. At the 1050° F. level, a columbium-stabilized austenitic steel of the 18% chrome–8% nickel columbium stabilized type 347 alloy has been used for turbines employing austenitic valves and shells, but within the past year the authors' company has modified its designs for the 1050° F. level, and, by holding the stresses to levels commensurate with the high-temperature strength of the 1% chrome–1% moly–¼% vanadium steel, is now using this ferritic material, which is relatively free of strategic alloys, for turbine shell, valve and pipe construction at this temperature level. The development of this ferritic design for the 1050° F. level is believed by the authors to be a distinct advantage to the nation's economy and defense as it enables industry to capitalize on the higher efficiency of the 1050° F. temperature without drawing to any great degree upon the nation's reserve of strategic materials.

At the 1100° F. level—and the authors' company now has commitments for two units at this temperature level—it is necessary to use the austenitic steels for high-temperature strength, but the gain in operating efficiency warrants the use of strategic alloys at this temperature level. In preparation for more extended construction at 1100° F., developments are now being pushed with great vigor to reduce the content of strategic alloys needed, and these developments already show considerable promise.

The authors wish to emphasize that the table of alloys vs. temperature presented in Fig. 6 is not intended as a general recommended practice for all manufacturers and all applications; this table is presented merely to illustrate the practice of this particular company in restricting the operating temperatures of various alloys. Other companies for equally good and sufficient reasons may have different rules for operating temperatures. Basically, and in a practical sense, there are no hard and fast rules exactly specifying the maximum operating temperature of the various alloys. In production design, however, it is necessary to set limits on the maximum operating temperatures of the various steels not only to obtain designs consistent among themselves, but also to ease the procurement and manufacturing problems. Since these temperature limits are arbitrary ones, practices will differ among the various engineering organizations, but the designs will all be satisfactory if the stress levels are commensurate with the material strength at the desired operating temperature.

Determination of Pipe Wall Thickness

To one unfamiliar with the many diverse views on this important practical problem, it would appear that agreement could easily be reached on a common method of calculating the necessary wall thickness of a pipe, since there are few stress problems which can be analyzed as readily as a pipe under pressure. That such agreement cannot be reached is due to some extent to the lack of a universally acceptable theory of metal fracture under multiaxial stresses. Because of this lack, elasticity experts have developed a number of theories, to which must be added conclusions based on yield strength and also the views of those of use who think in terms of average stresses. The subject of pipe stress formulas has been discussed in an excellent paper[5] by W. J. Buxton and W. R. Burrows which was presented at the 1950 Annual Meeting of the American Society of Mechanical Engineers, and much of the mathematical analysis of this section is taken from the Buxton and Burrows paper. This latter paper lists a total of ten expressions for calculating the stress in a pipe under pressure, and to this the present authors can add two more which will be discussed in the following presentation.

The basic expressions for calculating the stress distribution, in the elastic range, in a pipe under internal pressure were published by Gabriel Lamé in 1852 and, in the authors' opinions, his results are correct within their assumptions, and within the range expressed by these assumptions the authors have no objection. High-temperature piping, however, is definitely within the creep range when under operating conditions, which immediately nullifies Lamé's major assumption of elasticity, and renders his results inapplicable. The stress distribution should be calculated under assumptions applicable to creep phenomena, but here more difficulty is introduced by the lack of a universally acceptable theory of creep. For instance, some authorities postulate that the creep strain-rate is a function of the stress

alone, while others postulate that the rate is a function of both stress and creep strain. The expression published in 1931 by R. W. Bailey, and now termed the Bailey-Nadai formula, and which gives the stress distribution in a pipe under creep conditions, is based on a functional relation between creep strain-rate and stress, without regard to creep strain. However, the authors accept it as the best available at present, and in particular as being far more representative of the stress in high-temperature piping than expressions based on the assumptions of elasticity.

Figure 7 shows the elastic and creep stress distributions for a pipe whose ratio of outer diameter to wall thickness is 7, which corresponds for instance to a 14-in. pipe with a 2-in. wall. The dashed lines are the radial and tangential stresses as calculated for elastic conditions, and the solid lines are the corresponding stresses under creep conditions. The extra-heavy solid line is the shear stress under creep conditions. The stress distribution under creep conditions has been calculated in accordance with the Bailey-Nadai formulas with typical values taken for the necessary material constants.

The most striking result shown by the curves of this figure is how the tangential stress, which has a large maximum value at the inner surface of the pipe wall under low-temperature elastic conditions, reverses itself and has a (lower) maximum at the outside surface of the pipe wall under high-temperature creep conditions.

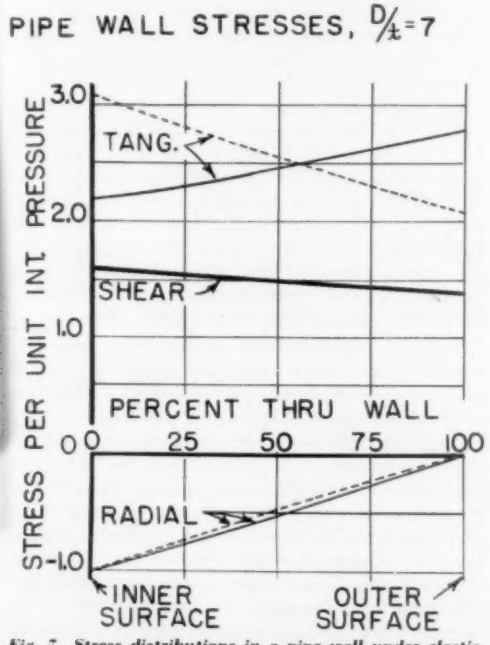


Fig. 7 Stress distributions in a pipe wall under elastic (dashed lines) and creep (full lines) conditions. Ratio of outside diameter, D, to wall thickness, t, of 7

The second striking result is the degree to which the tangential stress flattens out and approaches a simple average value.

In specifying allowable stresses for piping steels, the various national codes emphasize creep strength, and wall thicknesses are set, in general, in accordance with the 10^{-7} per hour creep rates (1% per 100,000 hr.). It is generally accepted that the creep rate, to a satisfactory engineering approximation, is a function of the shear stress, and for this reason, the shear stress is shown in this chart. Because the shear stress is a maximum at the inner surface of the pipe wall, it is evident that the creep rate will also be a maximum at the inner surface. In particular, the creep strain-rate at the inner surface will be greater than the creep strain-rate at the outer surface. Nevertheless, based on experience in high-temperature turbine design, there does not seem adequate justification, at least in the authors' opinion, for concern over this creep at the inner surface. The creep on the outside surface is the only strain which can be conveniently measured and might result in annoying dimensional changes, while the creep on the inside surface *per se* can do no harm, and it appears to the authors to be overconservative to demand heavy wall thicknesses just because of the inner surface creep.

To illustrate the degree to which the calculated stress in the pipe wall varies with different formulas, five expressions are given below for calculating wall stress, with D the outer diameter, d the inner diameter, t the wall thickness, p the internal pressure, and β a constant depending on the material and defined in Reference 5.*

1. The so-called Lamé expression which gives the maximum tangential stress under elastic conditions, and is the expression required by various piping codes:

$$\sigma = p\left(\frac{D^2 + d^2}{D^2 - d^2}\right) \qquad (1)$$

2. The stress at the *inner* surface of the pipe wall when calculated from the Bailey-Nadai expression for creep stress (equivalent tension):

$$\sigma = \frac{\beta p}{1 - (d/D)^\beta} \qquad (2)$$

3. The stress at the *outer* surface of the pipe wall when calculated from the Bailey-Nadai expression for creep stress (equivalent tension):

$$\sigma = \frac{\beta p (d/D)^\beta}{1 - (d/D)^\beta} \qquad (3)$$

4. The average-stress formula (sometimes called the common formula) which is based on the inner diameter, and which is in use in the ABS Interim Guide:[4]

$$\sigma = \frac{pd}{2t} \qquad (4)$$

5. The expression used in the Schenectady Turbine Divisions of the authors' company, and which is the

* A more detailed discussion of these formulas will be found in Reference 5 and its accompanying discussion.

above average-stress formula of (4) plus 20% of the internal pressure:

$$\sigma = \frac{pd}{2t} + 0.2p \qquad (5)$$

Using these five expressions, the calculated stresses per 1000 psi. of internal pressure are shown in Fig. 8 for a range of values of the ratio of outer diameter over wall thickness. For values of D/t of 10 or greater, all five expressions give about the same result, but for the heavier walls, as are required for modern steam temperatures and pressures, there is a significant difference. The so-called Lamé expression of (1) always gives a high calculated stress, but this expression has no significance under present operating temperatures because it is based on elastic analysis, and in the authors' opinion it is regrettable that so much design is based on this expression.

TANG. STRESS PER 1000 PSI INTERNAL PRESSURE

D/t	5	6	7	10	20	50
SO-CALLED LAMÉ	2120	2600	3080	4550	9530	24500
BAILEY-NADAI (INNER SURFACE)	2160	2670	3170	4700	9700	24700
BAILEY-NADAI (OUTER SURFACE)	1760	2270	2780	4270	9250	24300
AVERAGE STRESS ("COMMON" FORMULA)	1500	2000	2500	4000	9000	24000
FORMULA 5	1700	2200	2700	4200	9170	24200

Fig. 8 Pipe-wall tangential stresses per 1000 psi. internal pressure, as calculated by various formulas, for various ratios of outside diameter, D, to wall thickness, t

The highest stress is given by the Bailey-Nadai expression evaluated at the *inner* surface, and it is interesting to note that this expression almost duplicates the results obtained by the so-called Lamé, which duplication was presented in Reference 5. However, the authors do not believe that the creep at the inner surface is of any consequence, and in particular do not believe that pipe walls should be made heavy just to hold down the inner surface creep.

The Bailey-Nadai expression evaluated at the *outer* surface of the pipe wall gives calculated stresses which for heavy walls are significantly lower than the stresses evaluated at the inner surface. If the pipe designer has an application in which diametral creep could be of significance, this Bailey-Nadai expression evaluated for the outer surface seems to be the most applicable.

With regards to Formula 5, it is interesting to note how well this simple expression duplicates the more complicated Bailey-Nadai expression when the latter is evaluated at the outer surface. Within the range of D/t values considered here, Formula 5 differs from the Bailey-Nadai expression by less than 4% maximum.

The average-stress formula gives the lowest calculated stress, although this is no reason to assume it in any way inferior to the other expressions, as rupture considerations, to be discussed later, imply that it may be the most applicable of all. It should be noted incidentally that the D/t ratio must get below 7 before this average-stress formula gives a calculated value more than 11% below that of the Bailey-Nadai expression of (3). When one considers the scatter that is always present in creep-strength test results, an underestimating of this magnitude is of minor importance.

The foregoing discussion has dealt only with creep because various national codes, at least up to the present, have tended to consider creep and creep strength as the design factors of primary importance. To the authors, the design factor in most steam piping which is of primary importance is the rupture strength rather than the creep strength. In fact, there is considerable justification in the question as to why designers should be considerably concerned about creep in a properly cold-sprung pipe unless there are clearances which might be closed up by excessive creep. With regard, however, to the as yet undiscovered physical interrelation which must exist between creep strength and rupture strength, one can argue that the emphasis placed on the creep at the outer surface in the previous discussion is an error in judgment because the creep strain at the inner surface, being greater than that at the outer surface, could conceivably result in rupture failure by requiring too much strain. This is a point which definitely must be considered in piping calculations, but it is falacious to believe that setting the allowable stresses in terms of creep strength alone is a positive method of protecting against long-time rupture. The long-time rupture ductility exhibited by various alloys differs considerably, and further differences will be involved as harder alloys are developed for the higher temperatures. Protection against long-time rupture must be obtained by factors of safety based on the long-time rupture strengths of these various alloys.

The evaluation of rupture strength is plagued, admittedly, by the lack of a universally acceptable law of fracture under multiaxial stresses. Nevertheless, a satisfactory engineering result can be obtained by consideration of bursting tests on rotating wheels,[7] and of rupture tests of pins in shear.

Figure 9 shows the stress distribution in a rotating disk with a center hole when the stresses are all in the elastic range. In particular, the large tangential stress at the surface of the inner hole should be noted since, in an exaggerated fashion, this stress distribution is similar to that obtained in a pipe under internal pressure when in the elastic range. In spite of this large stress at the inner surface, failure does not occur, when this disk is slowly accelerated, until the speed is reached at which the *average* tangential stress throughout the disk cross section is approximately equal to the ultimate strength of the disk material. Applying this actual experimental result to the problem of the pipe under internal pressure indicates that, for consideration of wall rupture, the average wall stress as given by the average-

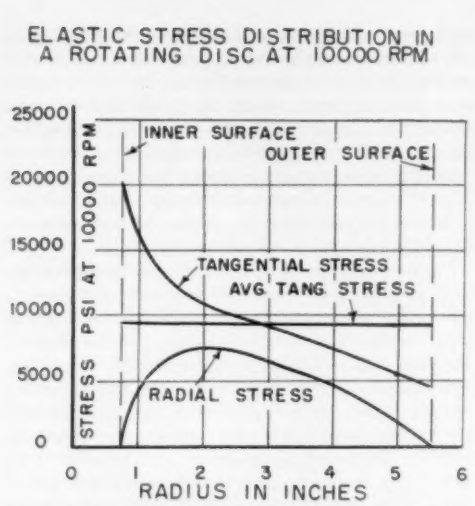


Fig. 9 Elastic stress distribution in a rotating straight-sided desk at 10,000 rpm. Outside diameter 11 in., with a 1/8-in. bore or inspection hole

stress formula is actually the most applicable criterion of safety of operation.

It can be argued, however, that tests on rotating disks are not directly applicable to pipes because the tangential and radial stresses in a rotating disk are both positive (tension), while in a pipe under pressure the corresponding stresses are positive (tension) and negative (compression). There is considerable merit in this argument as some test data are available which indicate that rupture may be controlled by shear stress. Test data on shear rupture strength are not available in the literature to any considerable amount, but tests conducted by the authors' company indicate that shear rupture strength is approximately 65% of tensile rupture strength. This value has been obtained both in room-temperature tests of dovetails in which the hooks sheared off, and in high-temperature tests of pins in straight shear, and although these tests were not conducted under "pure shear" stresses, it is believed that they are sufficiently applicable to the stress conditions present in engineering to permit their use in design, at least until the problem of rupture under multiaxial stresses is more completely understood.

Using the results of the rotating disk tests to the extent that they imply that rupture is controlled by the average stresses across the wall, the average shear stress can be written as in (6) in which the first term in the bracket is the average tangential stress while the second term is the average radial stress. The allowable shear stress, expressed in terms of the uniaxial rupture strength, is given by (6a) in which the factor of 0.65 is the experimentally determined observation that shear rupture strength is approximately 65% of the tension rupture strength σ_r, while F_s is the desired factor of safety.

$$\tau \text{ (av.)} = {}^1/_2\left(\frac{pd}{2t} + 0.5p\right); \quad \sigma_a \text{ for } \tau_{av.} = 0.65\ \frac{\sigma_r}{F_s} \qquad (6,\ 6a)$$

In Fig. 10 are shown calculated values of the ratio of p/σ_a in which σ_a is the allowable stress which itself is given, in turn, by the ratio of σ_r/F_s in which σ_r is the long-time rupture strength and F_s is the desired factor of safety.

High values of this ratio of p/σ_a mean that the designer can use higher steam pressure for a given allowable stress than could be used with the lower values of the ratio. The expressions which have been used for the calculation of Fig. 10 are as follows:

1. The average shear as presented in (6).
2. The Bailey-Nadai shear as calculated at its maximum value which is at the inner surface.
3. The average-stress, or common, formula, based on the inside diameter, as given by (4).
4. The Formula 5 which is simply the average-stress formula plus 20% of the internal pressure.
5. The so-called Lamé expression of (1).

The most conservative of these expressions is the so-called Lamé, which in the authors' opinion should be rejected as being inapplicable to high temperature rupture because of its elastic-stress basis. The next most conservative is Formula 5 which itself is well approximated by the average-stress formula of (4) for D/t ratios equal to 6 or larger. It should be remembered that these two latter expressions evaluate the potentialities of failure if rupture is a function of the average tangential stress as indicated by tests on rotating disks. If wall rupture is controlled by shear stress, the two shear expressions—the Bailey-Nadai shear stress evaluated at the inner surface, and the average shear stress of (6)—would both permit larger internal pressures than are permitted by Formula 5.

The conclusion implied by the results presented in this discussion is that Formula 5 is the most applicable

INTERNAL PRESSURE/ALLOWABLE STRESS : P/σ_a

D/t	5	6	7	10	20	50
AVERAGE SHEAR (FORMULA 6)	.650	.520	.433	.289	.137	.0531
BAILEY-NADAI SHEAR (INNER SURFACE)	.601	.487	.409	.278	.134	.0526
AVERAGE STRESS ("COMMON" FORMULA)	.667	.500	.400	.250	.111	.0417
FORMULA 5	.588	.455	.370	.238	.109	.0413
SO-CALLED LAMÉ	.471	.385	.324	.220	.105	.0408

Fig. 10 Calculated values of the ratio of internal pressure, p, to allowable stress σ_a considering rupture strength alone σ_a is given by the ratio of the long-time rupture strength, σ_r, to the desired factor of safety, F_s

and representative expression for use in the design of high-temperature piping. It evaluates to a satisfactory degree of exactness the creep on the outer surface of the pipe wall, and is the most conservative expression for evaluating the potentialities of long-time high-temperature rupture. (The so-called Lamé expression is not representative of high-temperature operation because of its elastic-stress basis any more than elastic stresses are representative of bursting tests on rotating disks.) For these reasons, the authors recommend that Formula 5 be adopted in the various piping codes, although the average-stress formula of (4) is sufficiently representative of actual conditions to be a satisfactory substitute, and so far as rupture is concerned may be the most nearly correct of all.

Cold Spring in Assembly

The philosophy of employing cold-springing to diminish the bending stresses which occur when the pipe expands from its room-temperature length to its operating-temperature length is in general acceptance, but the quantitative degree to which credit should be taken for the cold-springing varies considerably between various authorities. Briefly, if one cold-springs the pipe by the total amount it wishes to expand when hot, there will be (theoretically) no expansion stresses at the operating temperature, but the full expansion stresses will be present when the pipe is at room temperature, at which temperature it has its maximum physical strength. The Code for Pressure Piping, for instance, permits credit to be taken in cold-springing for only two-thirds of the actual amount of cold-spring up to a maximum value of one-third of the computed total expansion. In the opinion of the authors, this is a regrettable regulation since it tends to minimize the application of cold springing. It should be noted that if the piping is not cold-sprung 100%, bending stresses will be present at operating temperature, and due to creep these stresses will relax by self-springing of the pipe. Accordingly, after a long period of operation, the piping is approaching the condition it would have if it were initially cold-sprung 100%, so the installation ultimately contains the strains of 100% cold-springing without having obtained the design benefits of the lower stresses. Such operation has the deficiency, however, that it requires the cold-springing strains to be supplied by high-temperature creep, and under adverse conditions this may require more strain than is available in the material at the operating temperature. In the opinion of the authors and their associates, it appears better policy to utilize 100% cold-springing so that the maximum required strains are obtained immediately, and are present when the piping is in its most ductile condition. At the operating temperature, the expansion stresses will be at their minimum values, and it is not necessary then to rely on relaxation by creep.

It is true that the installed degree of cold-springing cannot be exactly determined, and cold-springing is not necessarily the exact duplicate of self-springing due to creep since the stress conditions are not necessarily exactly duplicated. However, it is the opinion of the authors that the partial credit which the national codes now permit for cold-springing is based to some degree on false conservatism, and should be increased considerably, and operating experience seems to verify this opinion. With our present demands on steel and alloy tonnage, our design practices should be carefully scrutinized as engineering in the present international circumstances cannot permit itself the luxury of over-conservatism, especially if poorly conceived. The practice of the authors' company with respect to the steam piping between the emergency stop valve and the turbine shell, when the stop valve is anchored, is to specify 100% cold-springing, and to take full advantage of this in the stress calculations. The expansion stresses are then evaluated in terms of the room-temperature strength of the piping steel, while the stresses at operating temperature are those due to pressure only and are evaluated with respect to the high-temperature strength.

There is considerable design philosophy based on the concept of avoiding even the smallest degree of yielding in a piping installation because it is construed as evidence of incipient failure, and in the authors' opinion this is somewhat overemphasized. It is rather interesting to see publications discuss theories of "failure" when they actually mean only yielding, which simply happens to be the failure of the elastic theory. Such philosophy seems particularly misplaced in view of the large amount of carbon steel piping which is cold bent and then installed without stress relief, or the number of pressure vessel parts which are formed by cold bending, and the successful operation which has been obtained with such construction. Another illustration would be cold-drawn tubing, while still another would be the number of piping specifications which state that the piping may be cold bent a minor amount if necessary.

To illustrate the degree of yielding which a pipe, under laboratory conditions, can withstand without cracking, Fig. 11 shows an unpublished experiment conducted several years ago by E. L. Robinson of the authors' company. This particular piece of ½% moly piping of 18.3-in. length was fixed at one end while the other end was displaced ±6.4 in. above and below the zero line. The calculated elastic stress (which is simply the strain times the modulus of elasticity) at the fixed end was 598,000 psi., which is obviously well above the yield point, yet this pipe withstood this test for 258 cycles before cracking developed. A similar pipe of length 21.5 in. and whose end was bent through ±0.963 in., and whose calculated elastic stress at the fixed end was 66,500 psi., withstood 1000 cycles without cracking, at which point the test itself was stopped. It is obvious, of course, that these calculated elastic stresses have no numerical significance since the yield point was exceeded, but they do show that yielding in itself is no indication of failure of the assembly. The only thing which has failed is the elastic theory.

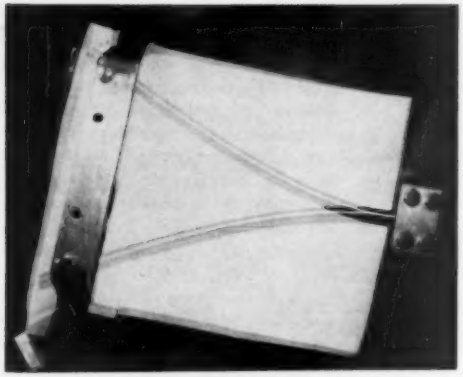


Fig. 11 Slow reversed-bending tests conducted on ½% moly pipe; end displacement of ±6.4 in. above and below the zero line. Pipe withstood 258 such cycles before cracking occurred

The authors, obviously, do not intend to convey the impression that land or marine piping installations should be subjected to strains of the order of magnitude of those used in the above test, nor, again obviously, are such strains used in the designs of the authors' company. Rather, these results are presented to make certain laboratory tests public, and to illustrate the degree to which most steels can withstand uniform yielding, and to stress the point that steel is normally a ductile material if given an opportunity of flow. Yielding should be looked upon primarily as the factor which can prevent cracking, but to do so the system must be designed so that yielding can occur if necessary. Figure 12 illustrates a welded pipe joint in which, due to a misunderstanding between the design engineers, the purchaser's consulting engineers and the field welding organization, this joint was welded and installed as shown. After only a few months operation at 950° F., this joint cracked through the wall, as shown in Fig. 12, for almost 180° F. of the pipe circumference. The crack started at the notch formed by the junction of the overlay bead and the continuation of the weld preparation, at which point yielding could not occur because of the restraining effect of the large masses of metal beside it. Only an impracticable degree of conservatism with respect to yield strength could have prevented this crack once the weld was made in this fashion. Cracks which occur due to notches formed by misunderstanding between the designer and the erector cannot be prevented by calculations at the design desk, but can only be prevented by an alert and competent field organization aware of the dangers present in stress concentrations at which yielding cannot occur.

Graphitization

No discussion of high-pressure high-temperature piping would be complete without a discussion of graphitization and its prevention. Graphitization is a completely undesired phenomenon in which the carbides in the steel break down and form graphite, which in the most serious cases migrates to a rather well defined line within the weld heat-affected zone about $^1/_{16}$ in. away from the original weld preparation. Here it tends to form into chains of an eyebrow formation as is illustrated in Fig. 13. These chains are graphite formations, and in severe cases of graphitization these chains can completely encircle the weld and give a plane of weakness which will crack through with no ductility, particularly under shock stresses as, for instance, when a valve closes suddenly.

The first case of graphitization[8] discovered in the field was in a steam power plant at Springdale, Pa., in which the main steam line broke apart during a valve closure. At this particular time, there was little steam pressure on the line, and no injuries resulted. Investigations initiated at the time of the Springdale failure, and continued in many quarters since then, have demonstrated that graphitization can be prevented either by employing a steel with as little as $^1/_2$ to 1% chromium, or by prohibiting completely the use of aluminum deoxidization in the manufacture of the steel. The authors' company has been successful in prohibiting aluminum in the manufacture of its large turbine castings, and has found no graphitization in any casting so made. It is not always possible, however, to obtain small cast fittings with the aluminum restriction, or to obtain piping which is aluminum-free, since aluminum deoxidization is usually desired in

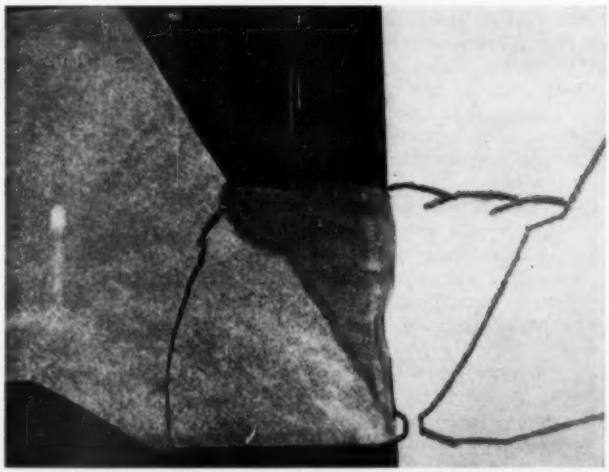
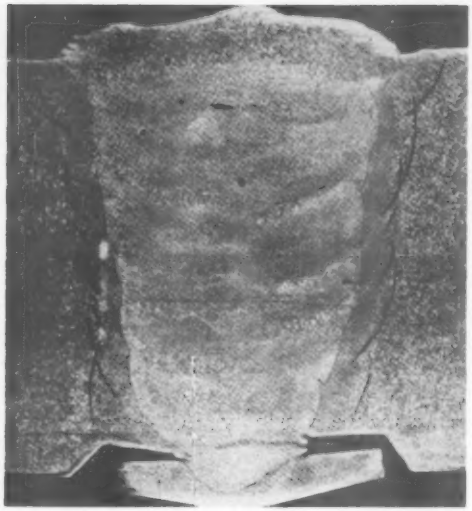


Fig. 12 Crack in a welded pipe joint due to notch concentration. Left side is photograph of section containing crack as removed from pipe; right side is sketch of remaining portion of weld and part of steam line



Courtesy, R. W. Emerson

Fig. 13 Welded joint exhibiting graphitization at extremity of weld heat-affected base material

quantity production to prevent imperfections forming on the cast surfaces, and to obtain adequate hot-workability in piping. Accordingly, the authors' company utilizes from $^1/_2$ to 1% of chromium in its piping steels in order to obtain adequate graphitization resistance, and recently has incorporated 1% of chromium in its shell and valve castings.

It is interesting to note, however, that no graphitization has ever been reported in the weld deposit metal itself, and it does not seem as necessary to insist on a high chromium content in the welding electrode as in the base material. It is believed, at least in some quarters, that harmful segregated graphitization occurs only in that part of the weldment which has been heated to a particular temperature, probably just above the lower critical, but it appears that stress is either a necessary adjunct or at least an important factor. In addition, a high operating temperature is required for a relatively long time. Basically, however, the phenomenon of graphite segregation in the form of chains is not yet sufficiently well understood that one can state definitely the fundamental cause.

Graphitization of steam power piping is costing this country many thousands of dollars, not only for its prevention but also to replace piping on which graphitization has appeared. Unfortunately, a great deal of power piping was installed at operating temperatures which promote the formation of graphitization before the industry was even aware of the need for protection against this phenomenon, and as this piping graphitizes it is necessary to either replace or rehabilitate it. It has been found, for instance, that the use of a high preheat and postweld temperature will either prevent graphitization or at least prolong considerably the time of its original appearance. Accordingly, in some cases it is possible simply to cut out the graphitized joint and reweld it with a high postweld temperature. In general, it has been found that the expense of probing every major weld in a power station, coupled with the cost of continuously policing the rehabilitated welds, is so great that it is economically better to simply replace all the major steam lines with chromium-containing steel, although in some installations it is more economical to simply replace the welds. The type of repair or replacement is an economic question which usually has to be considered for each individual installation. It is rather self-evident that the complete replacement of the piping is an extremely expensive solution, but it has already been employed in a number of large power stations as the cheapest solution for piping which has started to graphitize.

WELDING

Introduction

Up to this point, this paper has dealt exclusively with phases of the engineering design of high-pressure high-temperature piping, but the remainder of this presentation will be devoted to a discussion of some of the basic factors which contribute to the reliability of welded joints. No attempt will be made to present the more complex metallurgical phenomena, and the discussion will be restricted to the primary characteristics of the basic factors of joint design, preheat, electrode and postweld treatment.

At this stage in the development of steam power, little time need be spent on a discussion of the advantages of welded joints in piping as opposed to flanged and bolted connections. Where quick disassembly is not a significant factor, the advantages of light weight, low over-all cost, reliability and freedom from maintenance have resulted in an almost universal acceptance of welded connections in steam power piping. It should be noted, however, that the excellent performance of welded joints is due to a considerable degree to the maintenance of careful control of the complete welding procedure. While welding procedures may seem unduly complicated for the simple operation of joining two pipes together, it should be understood that each step in the welding procedure is planned simply to insure that the joint is sound after welding and that it performs satisfactorily in the intended service.

Joint Design

The basic intent of joint design is to insure that both sides are sufficiently accessible to permit fusion of the weld metal to the pipe walls, and to impose no undue hardship on the welder with respect to removal of slag. Primarily, the joint should be designed so as to give the operator as much freedom as possible to excercise his skill in welding.

Preheat

The role of preheat and its importance in the elimination of cracking is somewhat more complicated than the elements of joint design, but there are few factors which are more important. Figure 14 shows two welds made on chrome-moly-vanadium steel; the sound weld of the upper photograph was made with 400° F. preheat, while the cracked weld of the lower photograph was made with the same welding procedure but with the preheat eliminated. Incidentally, the lower weld was peened between passes, but this did not eliminate the cracking. With respect to the role of preheat, it is interesting to note that preheating was used on low-alloy steels for almost a decade before the scientific explanation was obtained of its function in preventing cracking.

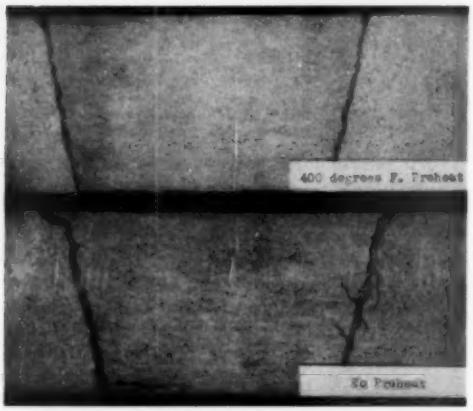


Fig. 14 Effect of preheat in preventing cracking on a chrome-moly-vanadium alloy. The lower weld was made with no preheat, while the upper weld employed a preheat of 400° F. Note cracking in lower specimen

In the old days of bare wire welding, weld cracking during fabrication was quite common, but such cracking was almost exclusively confined to weld bead cracking, and was quite obviously the result of lack of weld ductility because of oxygen and nitrogen pickup in the weld metal. The advent of the heavily coated electrodes, which provided an arc atmosphere of carbon monoxide, carbon dioxide and hydrogen, shielded the weld from the oxygen and nitrogen in the air, and eliminated, to a great extent, the weld bead cracking. It was puzzling, however, that a great many steels, which had been welded with a fair degree of success with bare wire, exhibited cracking in the base metal adjacent to the weld when welded with the heavily coated electrodes. It was known, however, that the alloy steels would harden when subjected to the thermal cycle and rapid quench imposed by welding, and accordingly the parts to be welded were preheated to some temperature above room temperature simply to decrease the cooling rate and thereby to obtain lower hardness, and with this preheating the cracking was alleviated. This seemed like a straightforward solution to the problem, but several inconsistencies existed, particularly since the cracking occurred to a much lesser extent with bare-wire welding, and did not occur at all when a heavily coated austenitic electrode was used. The use of either of these electrodes resulted in essentially the same hardness in the base metal adjacent to the weld as the new coated ferritic electrodes, so that hardness of the area obviously was not the sole cause of the cracking, nor were the benefits of preheating obtained only from the slower cooling rate.

Several investigations conducted during World War II then demonstrated that such cracking was not due completely to the metallurgical phenomenon of hardening which takes place in the base metal adjacent to the weld, but was due more to the fact that such hardening was taking place in the presence of dissolved hydrogen which was introduced into the base metal from the arc atmosphere during the welding operation. The solubility of hydrogen in iron is markedly affected by temperature as is shown in Fig. 15.[9] In particular, note that molten iron or steel can dissolve a much larger quantity of hydrogen than they are capable of holding in the solid state. While in the atomic form hydrogen is capable of diffusing through the crystalline structure of the steel, and as the temperature falls, the hydrogen will seek all possible avenues of escape to relieve the now supersaturated condition. If the diffusing hydrogen finds its way into a lattice vacancy or an internal void, such as resulting from solidification shrinkage, two atoms combine to form a hydrogen gas molecule, and as molecules collect, the trapped gas can exert sufficient pressure to rip the steel apart in a small area around a void.

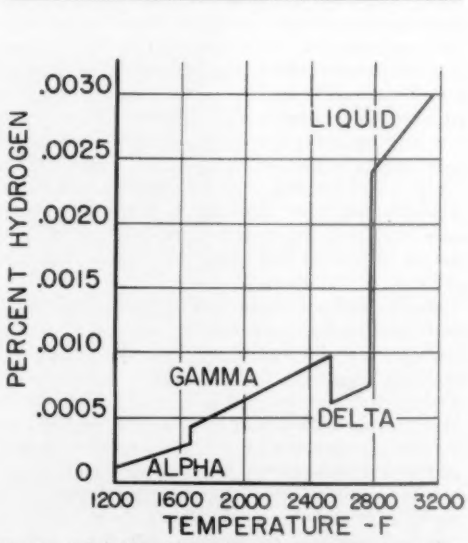


Fig. 15 Solubility of hydrogen in iron at one atmosphere pressure. (Copied from Welding Metallurgy[9]*)*

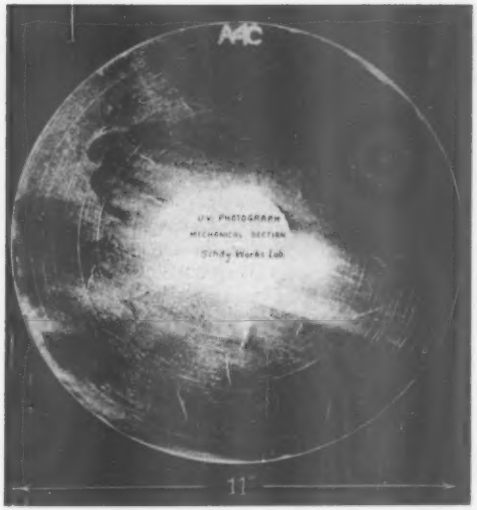


Fig. 16 Thermal cracks in the central 11-in. diameter region of a large rotor forging as shown by ultraviolet light and fluorescent magnetic powder

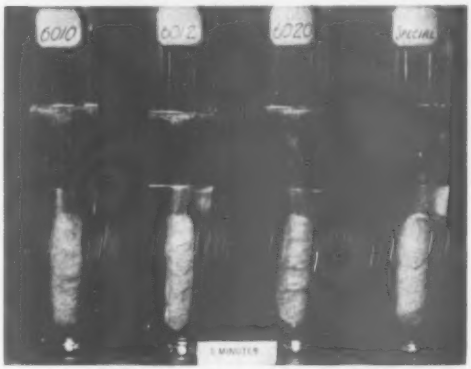
Cracking due to trapped hydrogen is not peculiar to welding since it can also occur in large forgings which have not been properly heat treated. On Fig. 16 is shown a disk cut from the center of a large rejected generator-field forging. The cracks shown here are thermal cracks, but they are similar in distribution and appearance to cracks in forgings caused by hydrogen entrapment. It should be noted that this type of cracking is extremely disturbing since these cracks do not always come to the surface, and accordingly are difficult to detect.

The major benefit of preheating during welding is now believed to be due to the increased diffusion rate of hydrogen which is obtained at preheat temperatures of the order of 400° F. since thereby hydrogen can escape more easily to the air, while the decreased cooling rate and lower hardness are believed to be of somewhat secondary importance. The lower hardness, obviously, is still of considerable benefit since a softer steel is usually better able to resist inadvertent notch concentrations, and in particular hydrogen trapping in a hard brittle structure will more quickly result in cracking than when trapped in a softer and more ductile structure.

Electrode Composition

In the early days of welding, the electrodes were bare wires, but, as mentioned previously, there was a lack of ductility due to oxygen and nitrogen pickup. Coated electrodes were then introduced which provided a shielding atmosphere around the arc by which the oxygen and nitrogen pickup were almost completely eliminated. The recent recognition that the hydrogen in the arc atmosphere is an important factor in weld cracking has led to the development and recent introduction of electrode coatings which produce arc atmospheres low in hydrogen, and these are the so-called "low-hydrogen" type of electrodes. Figure 17 illustrates hydrogen escaping from welds; the three welds on the left were made with the conventional electrodes which have a relatively heavy concentration of hydrogen in the arc atmosphere, while the weld on the right was made with one of the new low-hydrogen electrodes.

While the low-hydrogen electrodes produce arc atmospheres of less than 5% hydrogen as compared with the 40% present in conventional electrodes, this 5% hydrogen is still sufficient to cause underbead cracking if some hydrogen should be trapped, and an adequate preheat temperature must be maintained even with the low-hydrogen electrodes.



Courtesy, Arcrods Corp., Sparrows Point, Md.

Fig. 17 Hydrogen escaping from welds after 5-min. immersion. The three welds on the left were made with conventional electrodes while the weld on the right was made with a low-hydrogen electrode

With respect to the composition of the deposited metal, it is obvious, of course, that the weld must have adequate high-temperature strength and graphitization resistance. It is the practice of the authors' company to have the deposited metal match the pipe material in the alloys such as molybdenum and vanadium which are most effective in increasing the high-temperature strength. Chromium is used in the pipe material to increase the graphitization resistance, and is only of secondary effectiveness in increasing the high-temperature strength. Since there has been no evidence of graphitization in the deposited metal of welds but only in the adjacent heat-affected base material, it is the practice of the authors' company to require less chromium in the weld deposit than in the piping material, since the lower alloy content of the weld deposit tends to increase the ductility.

Postweld Treatment

The function of the postweld treatment is superficially

more apparent physically than most other aspects of welding, yet it is still the subject of considerable discussion. The postweld treatment has two major aims—stress relief and tempering—but these are separate phenomena and must be considered as such.

Due to the nonuniform heating and cooling imposed by the welding cycle, localized residual stresses are present in the region of the weld, and either the presence of these stresses or their partial removal by machining may result in distortion. Accordingly it is customary to subject the weld to a sufficiently high temperature that the yield point is lowered to the degree that the residual stresses can be minimized by relaxation, and this is the aim of a postweld stress relief. Figure 18 shows the relaxation of uniaxial stress in a specimen of chrome-moly-vanadium steel. The effectiveness of stress relief is much more dependent on temperature than on time since the relief is obtained primarily by reduction in the yield strength, and for this reason a postweld stress relief is usually held only long enough to reach temperature equalization. It should be noted, however, that the actual necessity for relief of residual stresses is still somewhat controversial as there is little evidence to date to indicate that residual stresses can contribute to failure when the design is such as to permit local yielding.

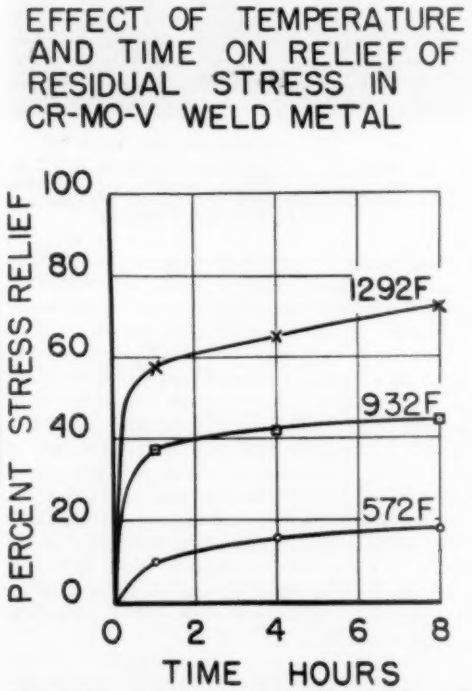


Fig. 18 Relaxation of uniaxial stress in a specimen of chrome-moly-vanadium steel as a function of stress-relief temperature

The tempering effect of the postweld treatment is required if the alloy composition is such that the fast cooling rate present in welding results in a weld deposit and adjacent areas with greater hardness than the base metal. Tempering differs from stress relief in that it is dependent upon both time and temperature, and, theoretically, one can be substituted for the other. Figure 19 shows the tempering behavior of the heat-affected zone of a weld in chrome-moly-vanadium steel as a function of time at various temperatures. This softening is dependent only on the temperature and the time at temperature, and is essentially independent of the heating and cooling rates so long as the postweld temperature is under the transformation temperature.

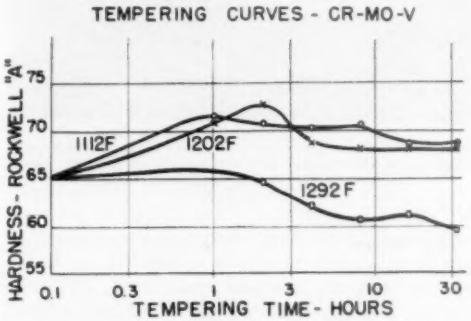


Fig. 19 Tempering behavior of the heat-affected zone of a weld in chrome-moly-vanadium steel as a function of tempering temperature

A major point which should be noted about the postweld temperature is its relation to the transformation temperature. If the piping is used in the annealed condition, which is its weakest condition with respect to high-temperature strength, then the postweld temperature can be above the transformation temperature, but if the piping is used in the normalized and tempered condition, which is its strongest condition with respect to high-temperature strength, the postweld temperature must be maintained below the transformation temperature to avoid weakening of the base metal.

An important point which should be noted with respect to normalized and tempered pipe as compared with annealed piping is the relative strength of the weld. By normalizing and tempering, the piping steel can be put in its condition of best high-temperature strength, but since it would not be possible to normalize and temper the welded piping installations, it follows that the welds in normalized and tempered piping are lower in high-temperature strength than the piping steel. This is not usually significant in piping since the major weld stress is axial rather than tangential, but in the design of turbine shells with welded-on steam chests, as shown in Fig. 20, the weld must be carefully designed to insure adequate high-temperature strength.

Fig. 20 Photograph of a turbine shell which utilizes split steam chest design. Long rectangular area at center of photograph is lower section of steam chest; upper half of steam chest will be welded on lower half at weld preparation shown above

Austenitic Piping

A discussion of welding would not be complete without mention of the austenitic stainless steels, which incidentally are now difficult to obtain because of their high chromium, nickel and, frequently, columbium content. It will be recalled that by heating the low-alloy steels above approximately 1330° F., the crystal structure begins to change from the body-centered ferritic structure to the face-centered austenitic structure, and this structure change and the accompanying changes in grain size are the basis of our heat-treating methods. With the steels of the 18% chromium–8% nickel family, this transformation is eliminated, and the steel remains austenitic at all practical temperatures. Because the transformation has been eliminated, the welding of the austenitic stainless steels differs in many important aspects from the welding of the more common ferritic steels. For instance, the solubility of hydrogen is greater in the austenitic structure than in the ferritic structure, and accordingly cracking due to hydrogen trapping is lessened; in addition, because there is no transformation, there is no possibility of forming the hard martensitic structure which is obtained by fast quenching of the ferritic steels. Accordingly, there is no need for a high preheat temperature in welding the austenitic steels, and none is normally used. The austenitic electrodes are used for many difficult field repairs in which the usual welding precautions cannot be maintained.

In the welding of stainless steel turbine shells by the authors' company, no preheat is used nor is any postweld treatment employed; in fact some welds are water-quenched after each bead. One should not reach the conclusion, however, that austenitic electrodes or the use of the austenitic stainless steels is the panacea for welding difficulties. The austenitic stainless steels have their own peculiar welding difficulties, and these can be far more serious than those which arise with the ferritic steels. In the case of large columbium-stabilized stainless steel castings, for instance, the grain size may be so large and the columbium carbide network such that considerable cracking may occur during welding.

A characteristic of the austenitic steels which sometimes makes them difficult to weld is that, while they have excellent room-temperature ductility, they tend to be "hot-short" or lacking in ductility near the melting point. This property of the austenitic steels makes them prone to intergranular cracking during the welding operation. It has been found that such cracking can be lessened if the heating and cooling cycle is as rapid as possible, which is obtained by dispensing with the preheat and specifying a maximum interpass temperature.

Another particular difficulty with the welding of the austenitic steels is the possibility of formation of a structure which has been called "sigma phase." This phase is not too well understood in a metallurgical sense, but physically it is extremely hard and brittle, and exhibits poor corrosion resistance. Its presence in a weld results in lowered ductility, and there is evidence that a postweld heat treatment can cause it to form to some degree. The postweld heat treatment for the ferritic steels is in the neighborhood of 1200° to 1300° F., but such temperatures are inadequate for the austenitic stainless steels because their high-temperature strength is so good that there will be little reduction in yield strength or relaxation of the residual stresses at these temperatures. To obtain adequate reduction in yield strength in the austenitic stainless steels, a postweld temperature of about 1650° F. is needed, but this is just in the temperature range which may promote the formation of sigma phase with a reduction in weld ductility. Accordingly it appears best to accept the lesser of the two evils, and where possible dispense with the postweld treatment entirely.* The formation of sigma phase is thus minimized, and while residual stresses are probably present, there is little evidence, as stated previously, that they will have any harmful effects in a structure designed with a minimum of notches. Accordingly the authors' company uses no postweld treatment in the welding of the austenitic stainless steels, and thus far has encountered no difficulties which could

* Recent developments have indicated that, with careful control, adequate stress-relief cycles may be developed which reduce to a minimum the possibility of sigma formation.

be attributable to the absence of either the postweld treatment or preheating. With respect to sigma phase formation, incidentally, while it is at present avoided as much as possible, there is already some thought that if it could be adequately controlled it might result in an excellent high-temperature steel, since a frequent characteristic of high-temperature steels is their unusual hardness.

ACKNOWLEDGMENT

The authors take pleasure in acknowledging the contributions of the many persons who participated in the formation of this paper. In particular, they express their indebtedness to R. M. Curran, D. L. Newhouse and E. L. Robinson, all of the General Electric Co., Schenectady, N.Y., for their advice and contributions.

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(*Continued on page 531*)

California's Proposed Fifteen-Million-Dollar All-Welded Freeway Viaduct in San Francisco

Review of some of the prewar welded bridges, the use of welding in bridge construction during the war and the contemplated use of welding in California's proposed fifteen-million-dollar all-welded viaduct in San Francisco

by Leonard C. Hollister

IN ANY engineering organization it is always easier, safer and much faster to follow the old tried and true designs of the past. Thus it is in the Bridge Dept. of the California Division of Highways where contract plans are prepared each year for millions of dollars worth of structures. Here for instance it would be much easier, safer and plans could be produced much faster if we designed only the tried and true "garden variety" of structures such as we are all perhaps familiar with.

However, we know that new developments are constantly being made in the three principal materials of bridge construction, namely, concrete, reinforcing steel and structural steel. And it follows that bridge engineers, too, must move forward in applying these new developments in materials and construction methods.

For instance the steel industry is constantly improving the steels available for construction purposes. Fabricators are constantly improving fabricating techniques. High-strength bolts are being investigated and developed to take the place of rivets. And as we look over the program for the Western Metals Congress, we see many talks listed on new developments in welding.

It is only natural then that bridge engineers, if they are to be progressive, must use, wherever advantageous, these new developments in the design of their bridges. Only in this way can the public receive the benefit of improved and more economical bridge and highway facilities.

Welding is a good example of the field in which improvements are constantly being made. While welding like many other advancements has been seemingly slow in being accepted and used to its fullest extent in the structural field, nevertheless today there is hardly a single bridge that does not make use of welding in some of its parts.

In 1931 the State built its first all-welded steel structure. M. B. McGowan was the contractor. This structure was 1380 ft. long and had a roadway width of 24 ft. This structure was a series of 40-ft. rolled beam spans supported on steel H-pile bents. The steel H piles were driven into the ground and the bracing for the bents was welded to the piles in the field. Steel caps were also welded to the tops of the piles and the 40-ft. stringers supported or framed into these caps.

Thus it can be seen that although this was an all-welded steel job, welds were used to transmit only secondary stresses. In looking over the final report for this job this interesting comment is noted: "Prior to the start of shop operations, the Bureau of Public Roads questioned the advisability of using a welded detail for the connection of stringer seat angles to the stringer. By agreement the detail was changed to provide a riveted detail at this point. This change embodies the sole exception to an all-welded structure." This, of course, is typical of the skeptical attitude at that time among engineers regarding welding of structures.

Another interesting note in the final report for this job was to the effect that there were 3100 linear feet of $^3/_8$-in. fillet welds to be made in the field which required a total of 1928 welder-hours. This amounted to 1.6 ft. of $^3/_8$-in. fillet weld per hour for the field welders. Of course, the welders received only $7.20 per day and the Pacific Coast Engineering Co. delivered structural steel to the job for 4.1¢ per pound and Soule Steel Co. delivered reinforcing steel to the job for 3¢ per pound. So when completed the structure cost in the neighborhood of only $3.20 per square foot.

The next all-welded steel job was built by the State in 1940 across the Kern River near Bakersfield. This structure was 1342 ft. long and consisted of twenty-two 61-ft. continuous steel stringer spans. On this job the girder splices were made by butt welding the stringers together in the field. All diaphragms and their con-

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nections were also completely welded. In addition to being an all-welded job the steel stringers were designed for composite action with the concrete slab by welding 2 x $^5/_8$-in. shear keys to the tops of beams to make them act integrally with the concrete slab. The job was described by G. L. Enke in "Design for Welding of 1941" and compared with a similar job using riveted splices and found to be very favorable from a cost standpoint.

The next all-welded job built by the State was in 1941. It was the San Juan Creek Bridge in San Luis Obispo County. This job was 260 ft. long and consisted of steel stringer spans, two at 43 and three at 58 ft. The stringers were continuous and had welded splices and details much like the Kern River job.

With the construction of the San Juan job, World War II interrupted the natural growth and development of bridge design in California. It interrupted welding except for one thing which is in a way very important. During the war it was necessary to build many access roads and structures, yet structural steel was very difficult to secure and waiting for rolled beams often meant excessive delays. Fabricators, however, often came to the rescue and offered to fabricate a beam or column of equal section modulus from plates welded by the submerged-arc process. At first the State and the Bureau of Public Roads accepted these welded beams reluctantly. However, before the end of the war, the welded-beam substitute for a rolled beam had become so common and was proving so satisfactory that it was in the end accepted without hesitation or reluctance.

With the start of the State's extensive highway program following the adoption of the Collier-Burns Highway Act at the close of World War II it was quite natural that welding should be used to a greater and greater extent. And today practically every structural-steel job uses welding to a considerable extent. For instance steel castings have practically been eliminated and welding is being used to fabricate shoes for bearing details, to make stiffener and diaphragm connections, to connect cover plates to rolled beams, to fabricate expansion joint details and in numerous other ways where welding has been found to have a definite economy and advantage over other types of fastenings.

In San Francisco one of the big freeway problems confronting the State has been the connection of the Bay Shore Freeway south of the city to the San Francisco-Oakland Bay Bridge. As finally worked out, the freeway called for the construction of a large viaduct with many "on" and "off" interchange ramps, extending from the San Francisco-Oakland Bay Bridge at 5th St. out to 17th St., a distance of over one mile, with a Y-extension leg west from Division St. to Van Ness Ave., a distance of about $^3/_4$ mile. This layout is

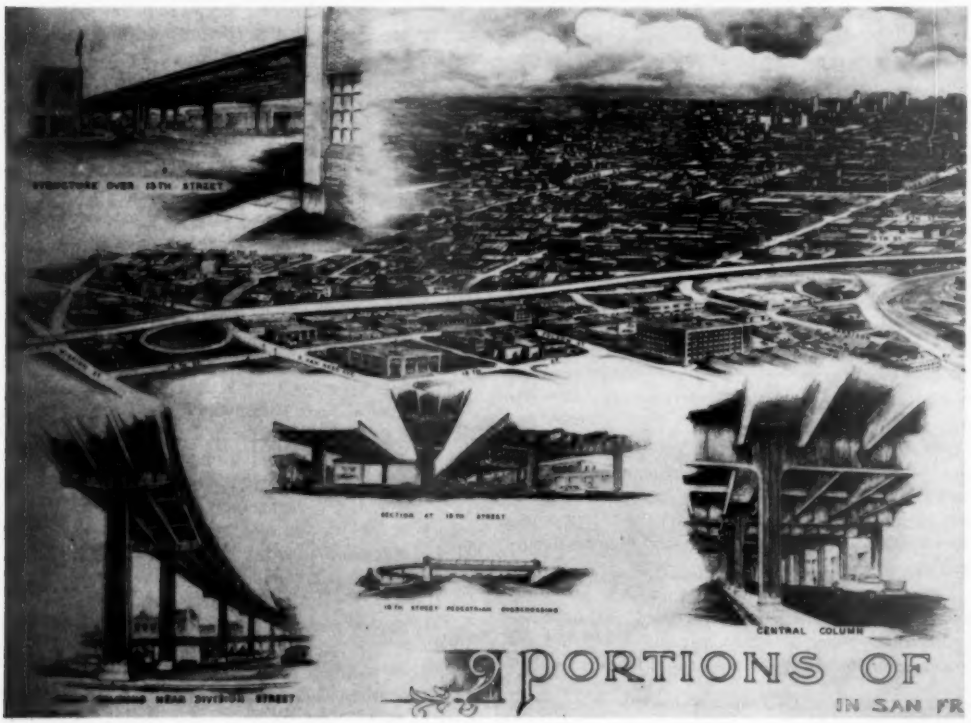


Figure 1

shown in the architectural sketch (Fig. 1) by Van der Goes.

In laying out and planning this structure many things had to be considered. Being such a large structure, economy of design was, of course, one of the first considerations. The structure will carry an immense volume of traffic (90,000 to 100,000 cars per day); therefore, safety and public convenience were very important considerations. The structure is in the heart of San Francisco; therefore, the aesthetics are very important. Foundations are extremely poor and in places must rest on piles 80 to 90 ft. long; therefore, the structure must be light in weight to be economical.

In order to make the structure as light as possible preliminary studies indicated that a structural-steel design had the preference over concrete. By using steel beams and making them act integrally with the concrete slab, a further saving in weight was effected by welding shear lugs to the tops of girders.

For example, most of the spans were approximately 57-ft. long and a conventional design would have required 36-in. wide flange beams at 280 lb. per foot. The composite design required a 36-in. wide flange beam at 194 lb. per foot, or a saving of about 4600 lb. per 57-ft. beam including the shear lugs and welding. In addition to the saving resulting from the reduced load on the footings there was effected a net saving in cost per each 57-ft. girder of approximately $300. And for the whole job this would amount to quite a large sum of money.

Preliminary studies indicate that there were still further savings in weight and metal resulting from the use of welded connections vs. riveted fabrication.

For instance the heavy caps showed a saving of about 20 to 24% by the use of welding.

Preliminary designs for the heavy steel columns indicated a saving of 12 to 15%, and in many of the heavy girders as much as 20%.

For the total job this saving could amount to 600,000 to 750,000 lb. of structural steel.

The reason for these savings was due to the fact that no reductions were necessary for rivet holes and because more efficient beam and column sections could be secured by placing the metal where it did the maximum good.

Except where determined by streets or railroad crossings span lengths are approximately 60 ft. and here rolled girders are used. To provide adequate clearance at many of the streets and railroad crossings spans must be larger and in some cases extend to over 100 ft. in length. To maintain the same architectural effect as the rolled beams of the shorter spans these longer spans were built up by welded plates making the girders similar in appearance to the rolled beams.

Figure 1

The longest of these was a 106-ft. span. These girders were made up of a 48- x $^3/_8$-in. web plate with 18- x $1^1/_2$-in. flange plate on top and 18- x $2^1/_2$-in. flange plate on the bottom. Thus this 106-ft. span is only 1 ft. deeper than the 36-in. rolled beams of other spans and maintains the same smooth appearance without rivet heads as the rolled beams. A section of this girder is shown in Fig. 2. As can be seen, provision has been made for a web splice by butt welding. The top flange has an 18- x $1^1/_2$-in. flange for the center 56 ft. and 18-in. x 1-in. x 25-ft. flange plates at each end. Where the $1^1/_2$-in. plate joins the 1-in. plate, the thicker plate is beveled down to 1 in. and the two plates butt welded to form a flange splice. Shear plates, 4 x 1 x 14 in., are welded to the top flange for shear keys to effect composite action. The bottom flange consists of an 18-in. x $2^1/_2$-in. x 58-ft. plate and two 18-in. x 2-in. x 24-ft. plates, beveled and welded as on the top flange. Stiffener plates 7 x $^7/_{16}$ in. at approximately 4-ft. centers are welded to the webs and seal welded to the top flange with a tight fit at bottom flange. Details provide for a welded field splice if the contractor elects.

The design as now laid out provides for only three different depths of girders:

36-in. rolled beams for spans to 60 ft.
48-in. welded girders for spans 60 to 106 ft.
54-in. welded girders for spans 106 to 116 ft.

Bents for the entire project consist of built-up welded steel columns and caps. There are in general 3-column bents, 2-column bents and single-column bents. The highest columns are in connection with the "on" and "off" ramps which have single-column bents and extend as high as 60 ft. To provide horizontal clearance at certain locations some of the single-column bents are channel-shaped. (See Fig. 1.)

The make-up of the column sections, of course, varies with design requirements. On the 3-column bents of the Y-extension to Van Ness the columns are made up as shown in Fig. 3 from 36-in. wide flange beams varying in weight from 230 to 280 lb. per foot, with two 1- x $6^1/_2$-in. plates welded to center web of beam and four 6- x $1^1/_2$-in. plates on four corners of flanges and two 3- x $1^7/_8$-in. plates welded to ends of center plate.

The columns for the 2-legged bents are made up as shown in Fig. 4 with 36- x $^3/_8$-in. web plate.

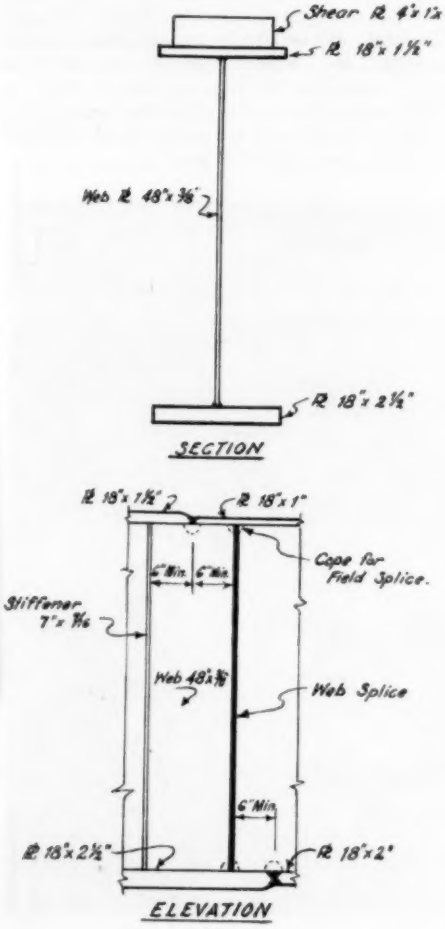


Figure 2

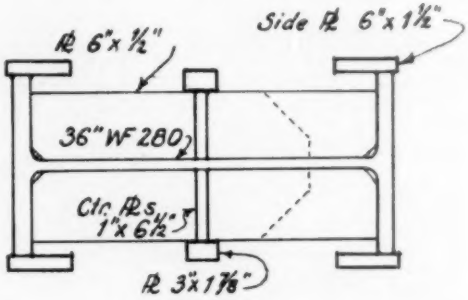


Figure 3

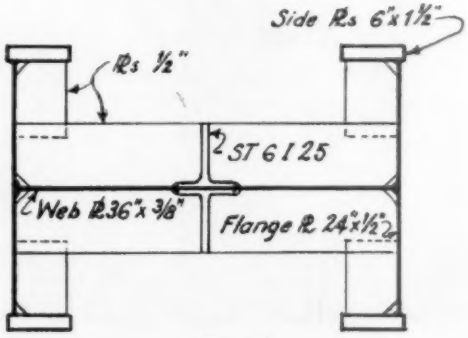


Figure 4

Two 24-in. flange plates, $^3/_8$ to $^1/_2$ in.
Four 6-in. side plates, $^3/_4$ to 2 in.
Two 6-in. T sections at 25 lb.

Column sections for the single-column bents are made up as shown in Fig. 5.

Web plate.....$^1/_2$ in. x $4^1/_2$ ft. at top, 1:60 batter
Flange plates...Two 24 in. x $^1/_2$ in.
Corner plates...Four 8 in. x $^3/_4$ in. to 2 in.
Center.....Two 8 in. WF at 40 lb.
Center.....Two 15-in. Channels at 50 lb.

Single-column bents eccentrically loaded are the heaviest column sections and are as shown in Fig. 6.

Web.....82 in. x $^5/_8$ in.
Flanges.....30 in. x 1 in.
Corner plates.....12 x $2^1/_2$ in.
Center.....10 in. WF at 45 lb.
Center.....15-in. Channel at 50 lb.

The cap and grillage beams are made up much the same as the girder sections. Some of the heaviest of these are made up of $^3/_4$-in. webs of varying depths up to 80 in. with flange plates 18 x $1^3/_4$ in. on top and 24 x $1^1/_4$ in. on bottom with 8- x $^3/_4$-in. stiffener plates.

These sketches give the general idea of the type and extent of welded sections used. For the entire structure there will be approximately 2,500,000 linear feet of welding.

From an erection standpoint details have been worked out so that bents can be erected ahead of girder erection. As soon as bents are erected, girders can be set in place on fabricated seats. Only about 15% of the bents will have to be tipped a small amount to facilitate seating and erecting the girders.

Expansion has been provided at one end of each girder. After deck has been poured and girders have taken their dead-load deflection, the end of girder opposite expansion is welded to the bents.

In preparing the special provisions for these contracts it has been the aim of the specification writers to specify the results that the contractor and fabricator must obtain rather than to outline methods to be used by him. The job has been designed for basic tensile working stresses of 18,000 psi. To take full advantage of the economic possibilities of welded construction it was necessary that many of the flange plates for these heavy sections have thicknesses over 1 in., requiring up to a maximum of $2^1/_2$ in.

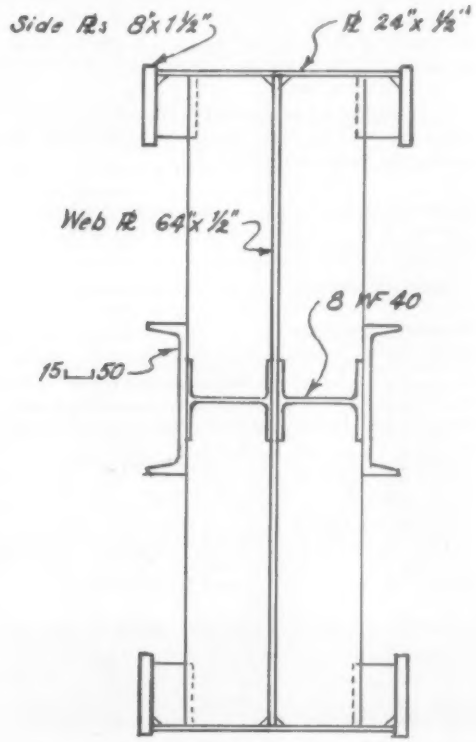


Figure 5

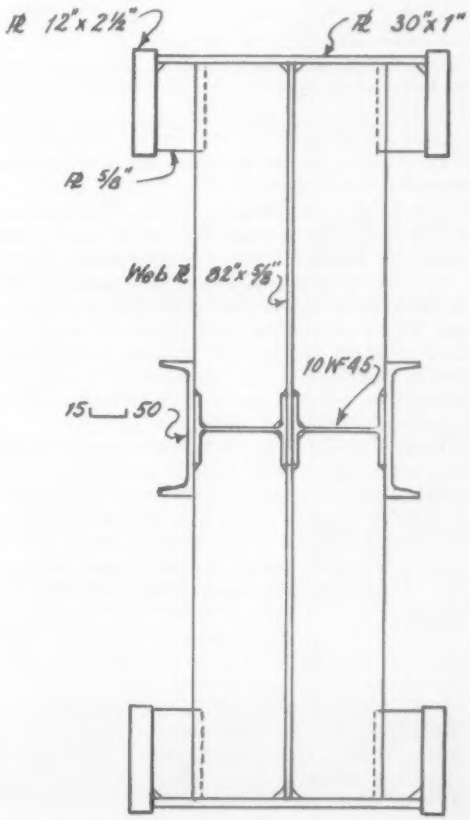


Figure 6

We know that in the manufacture of A.S.T.M., A7–49T structural steel the carbon content of heavy sections is increased well above the desired amount for easy welding. On account of this the determination of a material specification became a problem of considerable magnitude. After extended discussion with steel metallurgists and welding specialists, the following specification for the structural steel was decided upon:

Bars and shapes, and plates 1½ in. and less in thickness shall be structural steel conforming to the specifications of the American Society for Testing Materials, designation A7–49T.

Plates greater than 1½ in. in thickness shall be of steel made by either or both of the following processes: open hearth or electric furnace.

The steel shall conform to the following requirements for chemical composition, as evidenced by the specified ladle and check analyses, respectively.

	Analysis	
	Ladle	Check
Carbon, max., %	0.29	+0.04
Manganese, %	0.60–0.90	±0.04
Phosphorus, max., %	0.04	+0.01
Sulphur, max., %	0.05	+0.01
Silicon, %	0.15–0.30	+0.03 −0.02

The material as represented by test specimens, shall conform to the following requirements as to tensile properties:

Tensile strength, psi. . . . . 60,000 to 72,000
Yield point, min., psi. 30,000
Elongation in 8 in., min., % 21

The bending properties, as represented by test specimens, and the number of tests shall conform to the requirements specified for structural steel, A.S.T.M., A7–49T.

The grain size shall be from 5 to 8 in accordance with A.S.T.M. specifications, E19–46.

The general requirements for delivery shall be in accordance with A.S.T.M. specifications, A6–49T.

It is proposed to follow the Standard Specifications for Welded Highway and Railway Bridges of the American Welding Society with this exception:

In lieu of the provisions of Section 6, subsection 604, article (f) of the specifications of the American Welding Society specifying temperatures of contiguous areas to be not less than 130° F. when welding members of heavy section, the temperatures of contiguous areas about a welding operation shall be substantially equal, and not less than 300° F.

Furnace stress-relieving of built-up members (girder caps and columns), where material over 2 in. in thickness is welded to material of half its thickness or less, as specified under Section 6, subsection 604, article (g) of the specifications of the American Welding Society will not be required. Furnace stress-relieving of column bases, where so shown on the plans, will be required.

It was felt desirable to maintain some fabricating tolerances for trueness of shape and alignment of the beams, caps and column sections. The American Institute of Steel Construction has set up certain tolerances of rolled beams as to variation from theoretical depth and width, as to out of square or parallel and as to length and straightness. These tolerances were felt to be more refined than necessary for this particular construction and it is possible these tolerances may be increased by 100%. For instance the depth of the 48-in. welded beams should be within ¼ in. plus or minus of the theoretical depth rather than ⅛ in. as specified for rolled beams.

The total structure will cost in the neighborhood of $15,000,000 and will undoubtedly be the largest all-welded highway structure that has been built to date.

There will be approximately 1,300,000 sq. ft. of roadway equal to about 9½ miles of two-lane highway with an aggregate cost of about $15,000,000. This rather large amount of construction will most probably be broken up into five different contracts.

One of the early contracts to be let will be a portion about 1360 ft. long on 13th St. between Harrison and S. Van Ness Ave. requiring approximately 4,000 000 lb. of structural steel. This portion will cost in the neighborhood of $1,400,000.

Another portion will be the "on" and "off" connections to 9th and 10th Sts. This will comprise about 200,000 sq. ft. of structure requiring about 10,000,000 lb. of structural steel and costing in the neighborhood of $2,800,000.

The total amount of structural steel required for the entire structure is in the neighborhood of 61,000,000 lb.

We realize that fabricators have large investments in fabricating machinery and equipment based on the use of riveting, and some of the fabricators feel that they do not have the space for economical fabrication by welding. However, for the construction of such a large all-welded job fabricators should find it possible to set up space and equipment to handle welded fabricaton on an economical basis.

Following is a list of some of the jobs which are either under construction or in the design stage which use welding for main connections:

Williams St. O. C.	36-in. beams butt spliced
First Ave. O. C.	36-in. beams butt spliced
Warwick Rd. Pedestrian O. C. Campbell Ave. Pedestrian O. C. Marguerita Ave. Pedestrian O. C.	Built-up welded girders
Rt. 69/228 Sep. Str.	Built-up welded girders
Almansor Ave. O. H.	Built-up welded girders
Rio Hondo R. Br.	Split 36-in. beams welded web
Lincoln Ave. U. P.	36-in. beams welded cover plates
23rd St. O. C. 22nd St. P.O.C. 18th St. P.O.C. 25th St. P.O.C.	Built-up welded girders
Hesperian Blvd. O. C. San Lorenzo Cr. Br. Lewelling Blvd.	36-in. beams split welded web plate
Rubio Wash Br.	36-in. beam welded C. P.

No one can predict accurately what the future for welded highway structures will be. It appears, however, that with the success of this large $15,000,000 structure and these other fifteen or twenty jobs that we now have planned, fabrication by welding will move ahead rapidly on the Pacific Coast.

Tungsten-Thoria Electrodes for Inert Arc Welding

Tungsten-thoria electrodes overcome the erratic transition of the arc from the high-frequency spark to the actual arc

by N. A. Chapin, J. D. Cobine and C. J. Gallagher

DIFFICULTY is frequently encountered in initiating and maintaining a stable arc when using the inert-gas shielded welding process with direct current electrode negative. The difficulty in starting has been especially annoying on mechanized setups where the arc is initiated by superimposed high frequency. Attempts have been made to solve the problem of arc stability by creating a magnetic field around the electrode by the use of a copper coil (carrying direct current) around the nozzle. This helped somewhat to stabilize the arc but obviously could not be effective in initiating the arc.

The electrodes normally used with inert-arc welding are of pure tungsten and are essentially nonconsumable. Starting is accomplished by one of two means, namely, by superimposed high-frequency spark or by contact of the electrode with the work. Reliability of spark starting is dependent upon the previous history of the tungsten electrode. The transition from the high-frequency spark to an arc is often erratic, resulting in spoilage of work, especially with mechanized setups. The resulting arc is unstable and the arc cathode spot is highly mobile and frequently travels up the electrode, resulting in damage to the collet.

The initiation of a tungsten arc under typical welding conditions in argon is shown in Fig. 1. This shows consecutive frames of a movie taken at 50 frames per second. Frame 1 shows the high-frequency spark between electrode and work material. In Frame 2, the arc has been established and the cathode spot is already well up on the electrode. In frames 3–7, the cathode spot is up inside the nozzle and is apparently rotating as indicated by the electrode in silhouette in frames 6 and 7. The cathode spot is returning to the end of the electrode in Frame 8. The phenomenon shown photographically in Fig. 1 is shown schematically in Fig. 2, portraying the detrimental effect upon the weld.

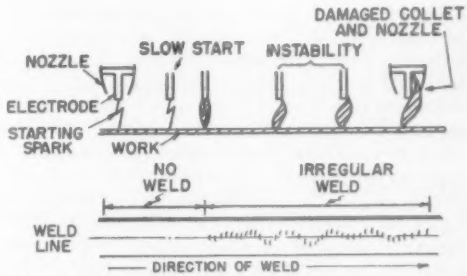


Fig. 2 Diagram showing bad effects of erratic starting

Under normal conditions, the transfer of current from the tungsten to the conducting gas is by evaporation of electrons from the hot metal (which is above the melting point of tungsten), i.e., thermionic emission. When such an electrode is cooled in the inert gas after arcing, it is left in a very clean state. In order that an arc be established by a high-frequency spark, it is necessary that a mechanism be established at the cathode capable of emitting a large current of electrons. When the tungsten cathode in inert-arc welding is cold and very clean, sufficient electrons are not emitted to establish an arc. It has been found that an oxide is necessary on the tungsten to supply the necessary emission.[1,2] The tungsten oxide formed by cooling an electrode in air is not usually reliable.

N. A. Chapin is connected with the Works Lab., and J. D. Cobine and C. J. Gallagher are connected with the Research Lab., General Electric Co., Schenectady, N. Y.

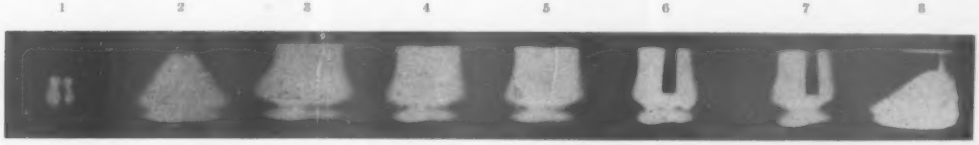


Fig. 1 Motion pictures of arc starting on pure-tungsten electrode with high-frequency spark (50 frames per second)

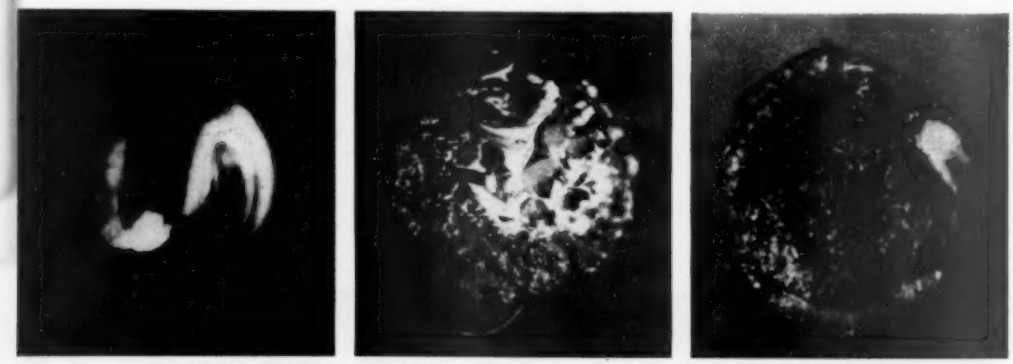
Table 1—Electrode Characteristics

	*Min. Dependable OCV for starting**			*Operating-current range, amp.*	*Failure current amp.,*
Work material (anode)†	Cu	SS	Si	...	...
Tungsten, pointed	>95	>95	>95	50–370	400
Thoriated tungsten, pointed (1% ThO_2)	40–65	55–70	70–75	10–350	385
High-thoria, pointed (15% ThO_2)	35	40	40	6–310	350

* 1/16-in. arc length, 15 CFH argon, 3/32-in. electrode, pointed, HF starting.
† Cu = copper, SS = stainless steel, Si = silicon steel.
NOTE: 95 is maximum OCV for welding generator used.

The problem of erratic starting and instability has been solved by the use of an electrode containing the necessary oxide. The refractory oxide, thoria (ThO_2), has been found to be the most satisfactory. Electrodes containing from 1 to 50% thoria have been tested for their starting and stability characteristics. Tungsten whose thoria content is of the order of 1% is known as thoriated tungsten and will be referred to as such in the rest of this paper. The criterion for evaluating starting characteristics was the minimum open-circuit voltage (OCV) required for reliable starting with superimposed HF spark (HF off after ignition) from a standard unit. Obviously, the best electrode is that requiring the least starting voltage, since less adjustment of the generator is required after starting, i.e., the generator can be preset to the required value and left there. Stability was easily determined by visual observation. Some of the more important test results are summarized in Table 1. These data indicate the marked improvement resulting from the use of thoria and the beneficial effect of higher thoria content. The minimum OCV for dependable starting with electrodes of thoriated tungsten was observed to vary over a considerable range, suggesting that there may be an effect of random distribution and exhaustion of thoria in the active zone. To verify this, electrodes of both the high- and low-thoria content were arced in argon for 1 hr. at 250-amp., d.-c., electrode negative, on copper. Following this, the electrodes were permitted to cool in the argon and the minimum open-circuit voltage for dependable starting was again checked. The thoriated-tungsten electrode would not start dependably at an OCV of 95 (upper limit of the generator) while the high-thoria electrode again started dependably at 40 OCV. This suggests that the small amount of thoria present in the thoriated-tungsten electrode was exhausted by this long period of continuous arcing, i.e., an aging effect. No effect of aging on starting has been observed for the high-thoria electrode, probably because there is always more thoria available than is needed for emission requirements.

Table 1 shows that the minimum OCV for dependable starting with unaged electrodes was dependent upon the work (anode) material. The minimum OCV increases in the order: copper, stainless steel, silicon steel. It will be noticed that the thoriated-tungsten electrode exhibits erratic starting, particularly at low OCV, as evidenced by the spread in the minimum OCV. For the more critical work materials, such as stainless steel and silicon steel, these voltages are very near the maximum available from welding generators—a very undesirable situation. When high-thoria electrodes are used, the minimum OCV is quite low relative to the generator voltage, and the observed range in starting voltage is negligibly small. Electrodes containing 15% thoria have been found to possess optimum characteristics. Thoria in excess of this amount does not seem to change the electrical properties of the electrodes. The full benefit of thoria does not become evident until the thoria content is approximately five per cent. Lower proportions exhibit random starting voltages which are relatively high compared to those obtained with the optimum thoria content. The use of the high-thoria electrode is especially desirable when welding silicon steel for which starting has been found



(a) (b) (c)

Fig. 3 Appearance of electrodes after arcing: (a) pure tungsten; (b) thoriated tungsten (1% ThO_2); (c) high-thoria electrode (15% ThO_2)

to be difficult with pure tungsten. The minimum OCV's for starting presented in Table 1 were obtained with commercial welding equipment, and are believed to be very conservative. In the case of the 15% thoria, regular starting in a laboratory setup was found with a copper anode at an average OCV of 23.3 v. with rms. deviation of 1.71 v. The difference in the two cases is believed to be due to differences in spark energy at the gap. The shorter leads used in the laboratory setup would increase the spark energy available at the gap and promote arc ignition.

Table 1 also gives the operating-current range for pure tungsten and for the thoria-bearing electrodes. The lower current limit is taken as the minimum current for which a stable arc can be maintained. The upper current limit is taken as the maximum current at which the electrode will operate without exhibiting radical changes in appearance over a ten-minute period. These changes have been observed to be either excessive melting of the tip, especially in the case of pure tungsten, or necking down of the electrode in the region above the tip. The latter condition is usually found in the thoria-bearing material.

The upper current limit given in Table 1 for pure tungsten is considerably greater than the 280 amp. recommended in the literature.[2] It is quite possible that a current of 370 amp. is well above that at which evaporation of tungsten becomes objectionable. Certainly at this current, the tungsten tip is molten, as shown in Fig. 3 (*a*). The thoria-bearing electrodes show considerably less melting at the upper current limit. For the 1% material (Fig. 3 (*b*)) there is some slight melting, and for the 15% material (Fig. 3 (*c*)) there is no melting. It is known that the temperature of the cathode spot is about 4000° K. for tungsten and 3300° K. for the 15% material.[2]

The last column of Table 1 shows the current at which failure occurred for the three electrode materials. In all cases, the failure appeared as a melting off of a short section of the electrode at the tip.

Although commonly practiced, initiating the arc by contact of the electrode with the work may result in contamination of both. This is especially true when "sticking" occurs. Electrodes containing thoria are much less susceptible to "sticking" than standard tungsten electrodes. There is evidence to indicate that increasing the thoria content further decreases the tendency toward "sticking."

There are certain important applications of inert-arc welding which require the use of low currents (10 amp. and below). This type of welding has required the use of tungsten electrodes as small as 0.010 in. in diameter, which presented major difficulties. The ease of starting and the stability of the arc with high-thoria electrodes have greatly simplified welding at low currents. These operations require very accurate positioning and control of the arc, which is accomplished by pointing the electrode.

In the tests reported above, argon was used as the shielding gas. Comparable characteristics were obtained when helium was used, except for a somewhat higher OCV required for dependable starting.

CONCLUSIONS

The use of thoria in tungsten electrodes results in dependable starting at low OCV, great arc stability and a wide operating-current range for a given size of electrode. These characteristics present obvious advantages for both manual and mechanized inert-arc welding with direct-current electrode negative.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of J. D. Coughlin and other members of the Works Laboratory and the Research Laboratory.

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(*Continued on page 543*)

Some Characteristics of Composite Tungsten Carbide Weld Deposits

Author's Reply

The author appreciates the comments that have been added and the questions that have been raised, as they are helpful in clarifying areas where brevity has prevented a full discussion.

The comment by Mr. Woods, pointing out the high rate of abrasion of a 1% carbon Cr-Co-W (at 450 Bhn.) alloy in comparison with mild steel (at 107 Bhn.), deserves considerable emphasis. This pattern has been comfirmed by repeated tests, and also in less striking fashion with other materials. There is a considerable volume of evidence, which cannot be detailed here, that justifies the statement that hardness should not be accepted as an index of wear resistance for hard-facing alloys, unless reinforced with other pertinent evidence. Even then, the area of such correlation should be carefully restricted.

The Cr-Co-W alloy that resisted grinding abrasion so poorly is the preferred material for valve facing, where oxidation resistance and hot strength are paramount and grinding abrasion is negligible. Even hot hardness data do not describe some of its unique virtues unless the technique is adapted to demonstrate creep resistance.

The surprise expressed by Mr. Woods over the difference between arc and gas welds is not unusual. It is one of the reasons that motivated the writing of this paper. The sometimes marked difference observed between gas and arc weld performance is not confined to tungsten carbide deposits. It has been noted by various research workers and for a number of hard-facing materials. It cannot always be simply explained, though weld metal dilution by fused base metal is frequently a part of the picture. Relative cooling rates, selective oxidation, carburization, temperature and perhaps other factors are involved. Mr. Wood pointed out the obvious differences in apparent granule content and distribution that appear in the weld photographs. We should like to emphasize that this difference in *trend* is important to any intelligent user of hard facing. However, we cannot accept the statement that the deposits shown are not satisfactory for field service, which makes the assumption of a single optimum type of deposit and a single service environment. We expect that the dense granule distribution of gas welds and of some arc welds will frequently outperform the scanty granule pattern of many arc welds, but there is also evidence that arc welds of the type Mr. Wood calls unsatisfactory have outperformed gas welds because of the superior toughness of the former.

To compare electrodes with welding rods for gas application (or arc and gas welding) on an oversimplified basis is like comparing two alloy steels without at the same time stipulating heat treatment and the final properties desired. When it is recognized that welding method and technique are as important to hard facing as heat treatment is to the utilization of engineering steels, the science of hard surfacing will be considerably advanced.

Mr. Woods has presented several criteria for good tungsten carbide granules and several hints for arc welding procedure.

The carbide used for this research will meet his criteria. It should be recognized, however, that the difference in solubility between compact chunks and flake or sliver-shaped pieces is minor in comparison with that from coarse versus fine granules, since the surface to volume ratio increases rapidly as size decreases.

The procedure hints are recognized as useful, and with the exception of preheating, which was omitted to reduce the number of complicating variables, were incorporated in the preparation of the welds used in this study. The research data explain the need for such procedure details.

Both Mr. Woods and Mr. Rogers seem concerned over the status of arc deposits and it was suggested that this paper was an attempt to prove the superiority of gas applications. This is not the case. The evidence that was encountered does show superiority under some conditions, but the reverse (such as the higher hot hardness of arc deposits) is also shown. Even the conclusions based on the assembled evidence do not postulate a general superiority of one method over the other. It is our thesis that *arc and gas weld deposits are different in character* and that the user should be fully aware of several important factors that can accentuate the differences. The field choice of the welding method should be based on the properties needed in the deposit. The engineering data for such a choice should not be biased by manufacturing interests intent on the sale of

Paper by Howard S. Avery and discussions were published in the February 1951 issue of THE WELDING JOURNAL, pp. 144–162.

gases, welding equipment or accessories except where it can be proved that the cost of deposition in relation to hours of service is pertinent.

Not all users are content with the choice between electric arc and oxyacetylene welding. Much of the hard facing of rotary rock drill bits is done by atomic hydrogen torches. The parts to be faced may be painted with a soluble silicate solution, carbide granules sprinkled on, and after the silicate has dried the carbides bonded on to the base metal by careful torch heating. Note that this promises properties intermediate between arc and oxyacetylene deposition. There is minimum carbide solution, contrasting with arc welding, but there is no carburization of the matrix as in usual oxyacetylene technique. The weld deposits are expected to be tougher than those where carbon is picked up.

A verbal question was asked about the base materials upon which tungsten carbide welds can be applied. This hard-facing material does not differ significantly from most of the others commonly used in its effect on the base. The associated problems are essentially those of base metal metallurgy, which includes transformation characteristics and crack sensitivity. Carbon from an oxyacetylene weld may diffuse into the base for perhaps 0.02 in. and confer the properties of higher carbon on the alloy base, which frequently increases cracking tendencies. This is unlikely with arc welding but the sharper thermal gradients may induce cracking. Much of the technique and ingenuity in hard-facing practice is demanded by the need for holding thermal stresses to a practical minimum. Preheating, postheating and the induction of transformation outside of the martensite formation range are important, and usually require base metal time-temperature-transformation diagrams for effective planning of welds on alloy steels. To minimize such complications the preferred welding base is a simple, killed carbon steel with the minimum carbon content that will provide satisfactory strength in the base.

Dr. Hess, in verbal discussion, asked if hydrogen embrittlement is a problem in tungsten carbide hard facing. The generally satisfactory results from the atomic hydrogen welding described above provides an answer to this.

Mr. Rogers has questioned the behavior of arc-weld deposits after rapid initial wear has taken place. Like the gas welds, the resistance to grinding abrasion improves if a more effective barrier of granules is encountered in depth. With coarse granules some arc deposits develop abrasion resistance comparable with that of gas welds, but they are likely to be exceptional. The general trend is more in conformation with that shown in Fig. 8. The alleged effect of refractory coatings on the granules seems plausible, but our laboratory tests are apparently not sensitive enough to detect it with assurance. Of course, if the refractory were completely effective the bond would not be satisfactory and the necessary alloying of the matrix would not occur. Delayed solution of the granules may possibly operate, but we believe it is considerably overshadowed by the factors of granule size and arc power. Since Mr. Rogers states that there is ample evidence of the kind that we have not been able to establish on this point, we suggest that publication of the details, with adequate statistical treatment to ensure the significance of the conclusions, would be welcome in the hard-facing field.

The matter of magnetic materials in the filler of tube rods has significance only in relation to specifications. It is difficult to justify an assumption that the addition of iron to the weld from the steel tube is any better than through the filler. The concern over cost to the user can best be made effective through a standardized specification that will define commercial limits for tungsten carbide and iron. This is now under consideration by the Surfacing Subcommittee of the A.W.S.-A.S.T.M. Committee on Filler Metals. At present there are no accepted standards for the industry. The formulation of rods now is a matter of each manufacturer's decision and since they are sold by trade names, they are unlikely to be exactly equivalent. If an attempt is made to argue the superiority of an additional 2 or 3% to tungsten carbide, it should be remembered that the expected gain in abrasion resistance, though very small, may be associated with less toughness in the deposit. Of much greater concern to the user is the fact that arc welding, even under the most favorable conditions, will increase the iron:tungsten ratio much more than incidental variations in the nominal 40:60 ratio of tube to filler.

It is pertinent to point out that some users insert an iron wire in the tube, displacing some of the carbide filler, and thus deliberately create a different iron: tungsten ratio in the direction of greater toughness.

The discussion generally highlights the variability of weld deposits. Unless this is taken into account in comparisons, field use, or field tests, there is considerable likelihood of being misled. We agree with Mr. Rogers that tungsten carbide is the best wear resistant hard facing for application where it is suited. We sharply disagree with the contention that the only reliable source of information for general usage is a practical field test.

Our company has specialized in wear-resistant materials for over fifty years and a great deal of effort has been expended on field tests. Much of the work has been done with castings where the variables are fewer than for weld deposits and where heat identification can be carried individually for each item tested with chemical analysis, heat treatment, and sometimes X-ray negatives of internal quality a matter of record. While not denying that field tests provide valuable information, it is a common experience to find that field tests are not reliable, using this word carefully in the sense of reproducibility. As a matter of fact, it is not usual to find field tests properly replicated to give an indication of reproducibility. Most industrial operating cannot be hampered by the control of variables that would make this possible.

We suspect that Mr. Rogers means valid where he uses the term "reliable." Obviously a field trial is more valid for the single event under consideration than any prediction based upon laboratory test data. The point

overlooked is the similar status of the field test evidence when the point of predicting performance on another trial somewhere else is reached. Unless the reproducibility of the first test as well as the validity of the correlation are known, the results of the second field trial cannot be predicted with assurance. The correlation problem is just as serious when two field tests are compared as when one of the tests is made in the laboratory, and the scatter bands involved are usually worse.

Even the same nominal application gives no assurance of comparability. The terms ball milling, or plow share service, for example, do not effectively circumscribe the significant wear factors involved. We recognize at least three distinct types of ball mill conditions and these are complicated further by variations in liner design. Depending on the type encountered, the preferred material may be austenitic manganese steel, air-hardening alloy steel or a martensitic cast iron. These three differ widely in resistance to impact and yet each serves best under certain ball mill conditions. Obviously the one best alloy for a specific mill cannot be arrived at with assurance from some previous "ball mill" field test result, without considerable insight about the factors involved.

Our common objective is to select or specify wear-resistant materials that give maximum life at minimum cost, and to reduce the guesswork in such selection. We shall serve industry best when we judiciously combine laboratory data, field tests, theoretical reasoning, close observation and judgment to aid our selections, rather than depend upon one narrow part of this complex pattern.

A Welded Factory Building in Italy*

A NEW structural fabricating shop has been welded recently for the Officine Bossi firm at Meda, 20 miles from Milan, Italy. Transverse and longitudinal sections of the building are shown in Figs. 1 and 2. A large part of the welding was done by a semiautomatic process which provided considerable savings in time and labor over manual welding. Design was based on a snow load of 20 lb. per sq. ft. and a wind pressure of 31 lb. per sq. ft. For the main steel work the design stress was 20,000 psi. while for the tubular roof structure the permissible design stress was 25,600 psi.

Details of the column and roof structure are shown in Fig. 3. Tubular construction saved a great deal of weight in the roof compared with conventional con-

* Abstract of "La nouvelle usine de la Société "Officine Bossi" à Meda, Italie," published in *L'Ossature Metallique*, **15** (12), 555-561 (Dec. 1950). (Abstracted by Dr. G. E. Claussen.)

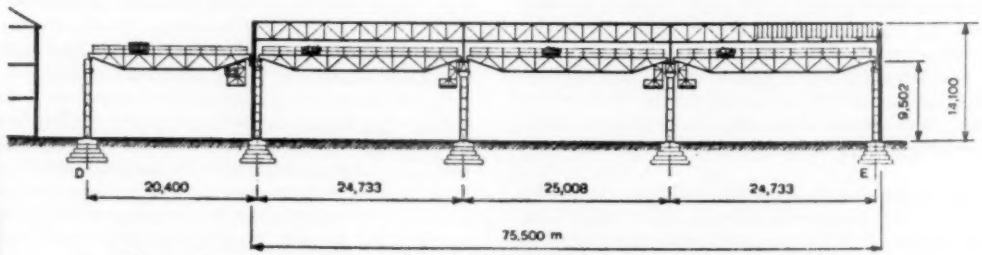


Fig. 1 Transverse section of the building. Dimensions in meters (75,500 meters = 248 ft)

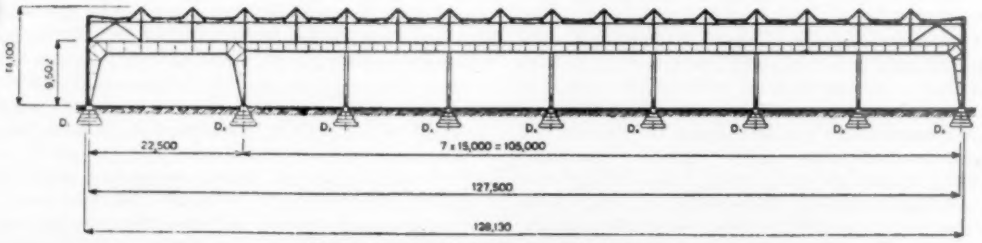


Fig. 2 Longitudinal section of the building

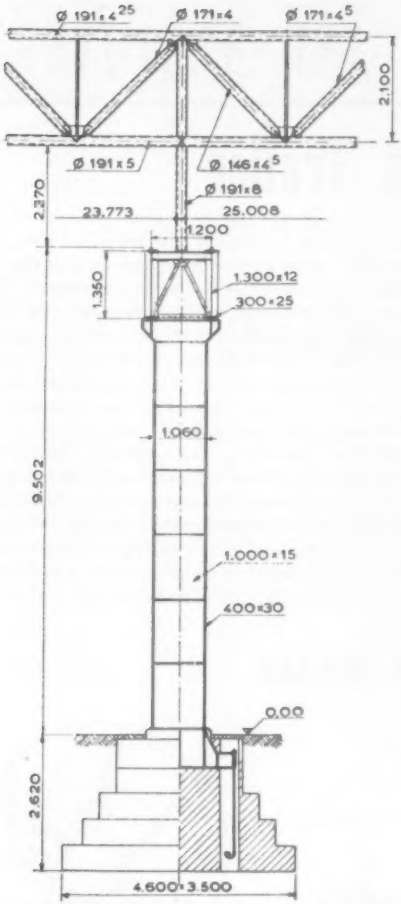


Fig. 3 Details of welded column and welded tubular roof structure. (Dimensions in millimeters)

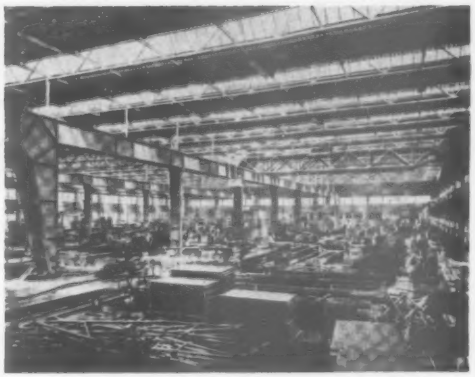


Fig. 4 Interior view of the building

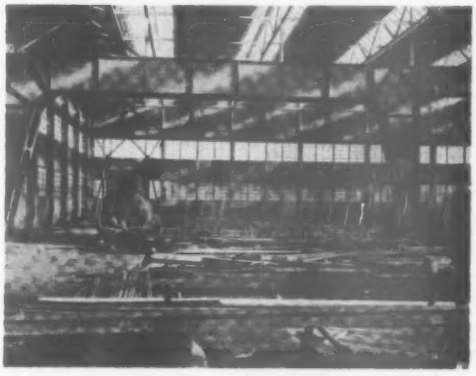


Fig. 5 View of one of the welded rigid frames

struction. The girders supporting the traveling cranes are continuous, Fig. 4. At one end they are welded to the rigid frame over the wide bay, Fig. 5, which has a span of 73 ft. In this way we achieved high rigidity and a noteworthy economy in weight. The crane rails were not utilized for resisting stress in the design. The rails are of Burbach type bolted to the flange of the girder, and are intended to be replaced eventually when worn out. Plate girders were preferred to trusses for reasons of esthetics and economy of fabrication.

PRACTICAL WELDER AND DESIGNER

Lift-Type Farm Trailer

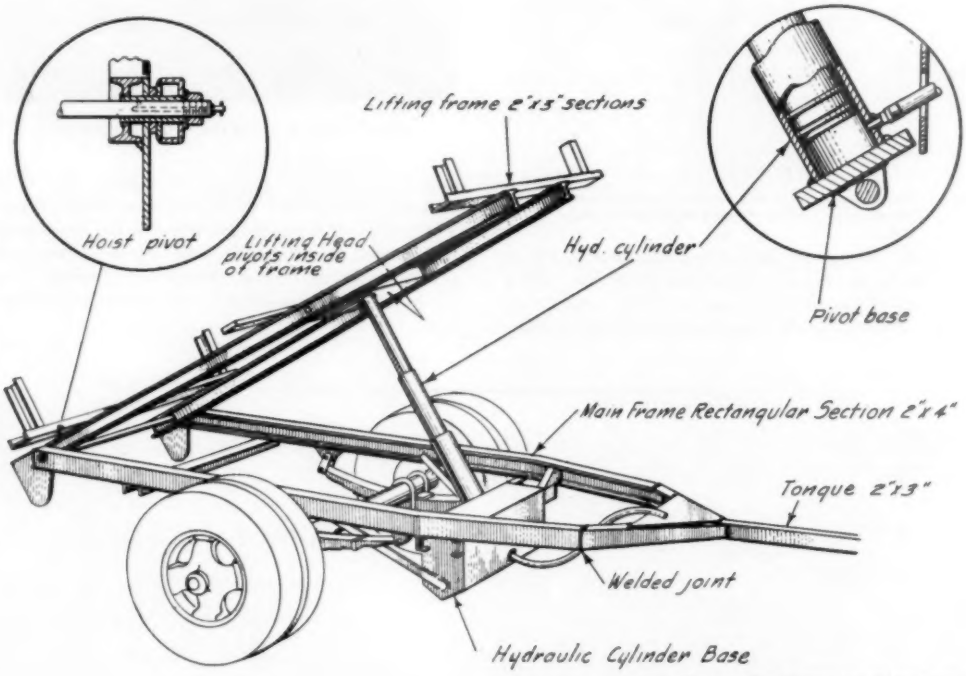
THE main frame can be made from channel as shown or can be readily converted from a car or truck frame. The lifting frame can be made from I-beams or channels.

The lifting frame pivots on the main frame by means of the 1-in. round bar axle or stud. A collar or washer should be inserted between the lifting frame and main frame to avoid binding. A grease fitting is recommended as shown in the inset sketch. Bumper plates can be welded to the rear of the lifting frame where desirable.

The lifting device consists of a hydraulic cylinder mounted on the hydraulic cylinder base. This base is welded to the frame and reinforced with steel straps. The hydraulic cylinder is welded to a plate which in turn pivots on a stud in the cylinder base. This pivot point must be well below the level of the main frame to provide initial leverage for raising the lifting frame. The hydraulic cylinder pivots also within the lifting frame by means of studs anchored into each side of the frame. The hydraulic cylinder has two sections with a compressed length of 21 in., yet with an extended length of 5 ft. to provide a maximum dumping angle for unloading any material. A hydraulic cylinder can generally be located at an implement dealer. The hydraulic cylinder hose is directly connected to a tractor hydraulic system, thereby saving the need for an additional hydraulic pump and driving device.

The axle is made of $3\frac{1}{2}$ in. tubing to which the wheel axles can be welded. The axle assembly is then held to the springs with "U" bolts in the conventional manner.

LIFT-TYPE FARM TRAILER



Sketch and Data Courtesy Lincoln Electric Co.

The springs in turn are anchored to the main frame with pivot plates cut from steel.

Bill of material:

2-in. channel
3-in. channel
3-in. I-beam
1-in. round bar
Dual wheels (4.5 x 16 truck-type tires)
1/4- x 2-in. steel strap
Hydraulic cylinder
3/16-in. plate
3 1/2-in. steel tubing
Springs
Flexible hydraulic hose
Miscellaneous grease fittings, bolts and washers

With this design, no front steering mechanism is necessary and the vehicle will back or turn in a radius as short as the tractor permits.

Two-Wheeled Carrier

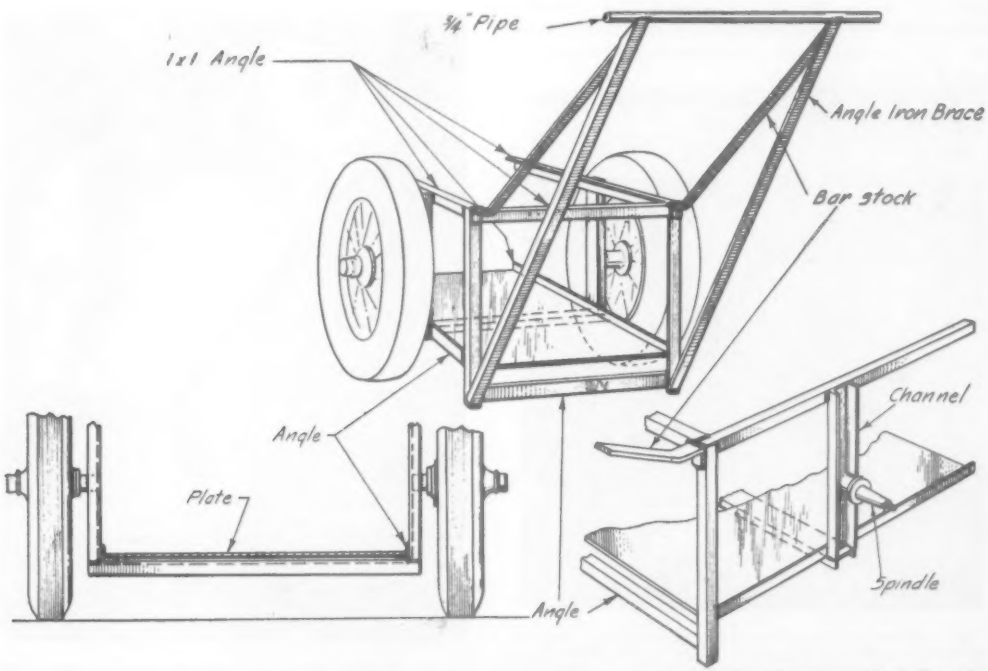
THE main frame is welded from angles and straps as shown. The axle is made from channel welded to the sides and bottom of the main frame. Regular automobile wheel spindles can be welded directly to the channel members.

The floor is made from steel plate cut to size and fillet welded to the main frame.

Bill of material:

1- x 1-in. angle
1 1/2- x 1 1/2-in. angle
2-in. channel
1/4- x 1-in. steel strap
3/4-in. pipe
3/16-in. plate
Two-rubber tired wheels
Two-wheel axles

TWO-WHEELED CARRIER



Sketch and Data Courtesy Lincoln Electric Co.

High-Strength Pressure Vessel

A NEW achievement in fabrication of extremely high-strength pressure vessels has been recorded by Research Welding and Engineering of South Gate, Calif., with completion of a welded stainless steel spherical storage chamber for use by the U. S. Air Force in rocket-propelled aircraft experiments.

The vessel is stressed to contain 200 gal. of liquid nitrogen at 5500 psi. pressure and at −340° F. with a comfortable safety tolerance.

Research Welding, which specializes in fabrication of high strength equipment required for advanced propulsion devices, constructed the vessel—nicknamed the "Nitro-Sphere"—from stainless steel plate stock measuring $3^{11}/_{16}$ in. in thickness. The sphere measures 54 in. in diameter and weighs approximately 7500 lb.

The relatively low weight is credited to the unique high stress design. Alternate proposed designs, providing for a barrel-type structure, would have ranged in weight up to 15,000 lb.

Significant in fabrication of this high-strength structure was the use of Dy-Chek, the dye penetrant method, for inspection of all welds at frequent intervals in the assembly process.

Research Welding and Engineering built the Nitro-Sphere as prime contractor for supplying a complete nitrogen ground storage and manifolding system to the Air Force for use in servicing experimental rocket-propelled aircraft.

John A. Toland and William F. Bennett, co-partners of the firm, personally directed the design and choice of fabrication processes for the vessel.

An "exploded" cube layout was chosen inasmuch as it appeared to offer highest strength potentials.

Allegheny-Ludlum supplied six 3.687- x 38- x 38-in. stainless steel plates, rolling them as a special lot from 347 ASTM-A240 Grade C stock at its Coatesville, Pa., mill.

Research Welding arranged for The National Supply Co., Torrance, Calif., to form the plates to 22.500-in. spherical radius. National Supply prepared a die and punch and pressed the plates to shape after preheating them to 1700° F.

The plates were then laid out in the Research shops, and were trimmed on flame-cutting equipment at the nearby facilities of Jorgensen Steel Co. An interesting innovation in layout enabled the shaped plates to be both trimmed and beveled in the same operation.

A heavy duty grinder was used to remove slag and residue from the trimming operation. To insure against contamination, the parts also were pickled.

The parts were then fitted and held temporarily in place with thin backing plates. Attesting to the quality of the workmanship, all segments conformed symmetrically, and there was no joint misalignment.

As welding specialists, Research specified exacting weld procedure for the sphere. First weld passes were made with Heliarc welding. These welds were then subjected to inspection by both Gamma ray and Dy-Chek.

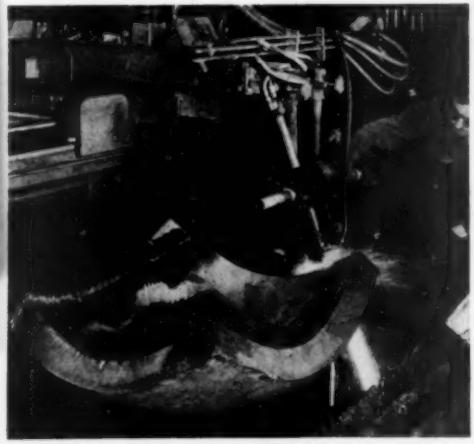


Fig. 1 After forming, plates were trimmed and beveled in one operation on this flame cutter at Jorgensen Steel Co. Use of flame-cutting equipment saved an estimated 30 days' fabrication time

Fig. 2 Multiple-pass arc welding was used to join shaped plates. Nearly one ton of weld rod was used

Fig. 3 Dy-Chek inspection was used repeatedly during the multiple-pass welding process to check integrity of welds. Here sphere is being inspected at an early welding stage

"In structures of this type, we consider weld inspection most important," declared Toland. "By combining both Gamma ray and Dy-Check, we feel we are able to establish without question the integrity of the weld. Dy-Check, as a surface penetrant, will not necessarily reveal internal flaws. However, it definitely will detect flaws that might not be discernible by other methods. Consequently, the combination of two inspection processes was used."

Following inspection of the first weld passes, the joints were filled by multiple-pass arc welding. General Electric Type 1347 $^{3}/_{16}$-in. diameter coated electrode metallic arc rod was used. In all, nearly a ton of weld rod was used on the job. The combined Gamma ray and Dy-Chek inspection processes were repeated several times as the welds were built up.

Final operation was application of heat treat to achieve a full annealed condition. The sphere was heated at 1950° F. for $3^{1}/_{2}$ hr. and then subjected to both internal and external quenching through use of high pressure jets.

It then was subjected to hydrostatic test at 10,000 psi. pressure in the Research company's test chamber.

Lastly, the Nitro-Sphere was again inspected with both Gamma ray and Dy-Chek. It now is ready for use by Air Force research teams in their experiments to extend man's conquest of flight at supersonic speeds.

Flame-Cutting Slotted Pipe

PRODUCTION time was cut approximately 80% when flame-cutting was substituted for milling on a pipe-slotting contract. The contractor also reported a considerable saving in costs.

The job consisted of cutting approximately 3000 slots, 8 in. long by $^{5}/_{16}$ in. wide, in 40-ft. sections of pipe. The pipe wall thickness was $^{3}/_{8}$ in. It was to be used as well screen in an irrigation well of the City Water Works of Eagle Pass, Tex. The contractor was the Alamo Iron Works of San Antonio, Tex.

Milling was originally planned for the job, but it developed that milling would require 500 machine hours. Flame-cutting was then tried and adopted. In all, 2700 linear feet of cutting was completed in 103 operator-hours. A blowpipe with a special two-nozzle coupon adaptor was mounted on a portable cutting machine to cut both sides of each slot in one pass. Drilled holes started the cuts, and the result was smooth, even cuts that required no finishing. Oxygen consumption for the job was 1380 cu. ft. and acetylene consumption was 200 cu. ft.

Fig. 1 An operator starts a slot cut in pipe 18 in. in diameter, and $^{3}/_{8}$ in. thick. A two-nozzle coupon cutting adaptor is attached to the blowpipe so that the $^{5}/_{16}$-in. wide slot can be cut in one pass. An Oxweld portable cutting machine is being used to mechanize the job

Design Data for Brazing—Part II

The material presented is design data recommended by the Welding Section of the Schenectady Works Lab. and is being used by Design Engineers within the General Electric Co.

by W. J. VanNatten

II. FILLER METALS AND FLUXES

IN GENERAL, brazing filler metals can be divided into four groups, each group having its own field of application. The following sections explain the advantages, limitations, composition, characteristics and recommended clearances for the four groups of brazing alloys and fluxes.

A. Copper Filler Metal

Brazing with copper filler metal is generally limited to ferrous alloys and other high melting point alloys. Brazing with this filler metal is usually done in a furnace with a protective atmosphere. A flux is not necessary when brazing low-carbon or stainless steels if the proper reducing atmosphere is maintained.

Copper filler when heated above 1083° C., its melting point, flows over the surface of the metal like water. It may be preplaced in the form of commercial (tough pitch) copper wire, sheet, copper oxide powder, or copper sprayed on.

The following table shows various fits and corresponding shear strengths for those fits. These data are based on brazing low-carbon steel to low-carbon steel.

Tightness of fit	*Shear strength, psi.**
0.002-in. drive fit	31,000
0.0015-in. drive fit	30,000
Snug fit (no gap)	28,000
0.003-in. clearance	22,000

* These values are the maximum ultimate shear strengths for design purposes. Use a factor of safety.

Caution: Parts whose clearance exceed 0.003 in. are not recommended as they may produce joints with an excessive number of voids, low shear strength, and in some cases may require running through the furnace more than once to fill gaps with copper.

W. J. VanNatten, Welding Section, Schenectady Works Lab., General Electric Co.

Where relatively high service temperatures are required, brazing with copper filler is generally recommended. The temperature to which such a brazed joint may be subjected naturally depends on the stress on the joint at a particular temperature and the surrounding atmosphere.

B. Silver Alloy Filler Metals and Fluxes

It can be seen from the base material chart, Section I, that most ferrous and nonferrous alloys may be joined using various silver alloy filler metals.

There are countless numbers of silver alloys on the market today. Some alloys which find widespread use are listed in chart form, Table 2.

C. Aluminum Alloy Filler Metal and Fluxes

Filler Metals

The following alloys are used as filler metals in brazing aluminum:

Designation	*Copper*	*Silicon*	*Zinc*	*Aluminum*	★ Critical Temperatures ° C. mp	° C. fp	° F. mp	° F. fp	*For brazing base metal*
(1)	...	7.5	...	92.5	577–618		1070–1135		28, 38
									28, 38
(2)	...	12.5	...	...	577–582		1070–1080		538, 618, 638

* See footnote Table 2

(2) brazing alloy is the general-purpose aluminum alloy filler material with (1) flux as the general-purpose flux.

Brazing Sheets

There are many applications where it is advantageous to have the brazing alloy incorporated on the base metal. Brazing sheet has a brazing alloy coated on one or both sides of the base metal core. There are a number of different types of brazing sheets commercially available and they are tabulated as follows:

Designation	*Sides coated*	*Thickness of coating, in.*	*Type core*	*Type brazing alloy*	*Brazing temperature* ° C.	° F.
B	1	10% up to 0.063	38	(1)	588–616	1090–1140
B-B	2	5% over 0.063	38	(1)	588–616	1090–1140
C	1	10% up to 0.093	J518	(1)	588–604	1090–1120
C-C	2	5% over 0.093	J518	(1)	588–604	1090–1120

Table 2—Common Silver Brazing Alloys

	Use	Chemical composition, % Ag	Cu	Zn	Others	*Critical temperatures ° C. m.p.	f.p.	° F. m.p.	f.p.	Elec. cond. Cu = 100%	(2) Recommended joint clearance, in.	(1) Shear strength, psi.	Remarks
General-purpose silver alloy filler metals	B1	45	15	16	24 Cd	608	618	1125	1145	...	0.0015–0.006 for ferrous materials 0.002–0.008 for nonferrous materials	38,000 36,000	Lowest temperature general-purpose silver alloy for brazing. Best alloy for applications where excessive heating of base material is objectionable. It is very fluid good penetration of the joint. Forms small fillets when properly used. Should not be used when the heating cycle is relatively long, such as furnace brazing heavy parts, as the zinc and cadmium tend to boil out of the alloy. Flux (3) is recommended for use with this alloy.
	B2(a)	15	80	..	5 P	640	700	1185	1292	10.0	0.005–0.015	...	This is the lowest-cost silver alloy in this group for brazing. Recommended for use on silver, copper, copper alloys. This alloy should not be used on any ferrous material. No flux is required where brazing is done rapidly. Where the brazing operation takes considerable time use flux (3). Preloading of joint when using this alloy is preferred whenever possible as this alloy is not as free flowing as B1. B2(a) or B2(b) should not be used where sulphurous atmospheres are in evidence. B2(b) is only supplied in the form of extruded shapes.
	B2(b)	15	78	..	7 P	640	700	1185	1292	...	...	...	
	B3	50	15.5	15.5	16 Cd, 3 Ni	646	688	1195	1270	...	0.003–0.008	...	This alloy used on materials such as tungsten, molybdenum and cemented carbides which are hard to wet. Wherever possible the base material should be presilvered with brazing alloy, cleaned, refluxed and the presilvered base metals brazed together. This brazing alloy forms large fillets. Flux (3) is recommended for use with this alloy.
	B4(a)	50	34	16	...	690	775	1275	1425	24.4	0.002–0.008	Equal to or better than B1	Medium temperature silver alloy for brazing. It wets and flows well and has high strength and ductility at room temperature. It is suitable for applications where large fillets are required. Flux (3) (paste type) or flux (4) (powder type) is recommended for use with this alloy. For applications requiring metal bath brazing this alloy is preferred.
	B4(b)	30	38	32	...	745	790	1370	1450	...	0.002–0.008	...	Medium temperature silver alloy for brazing. Does not wet or flow quite as well as B4(a) but costs a little less. This alloy not recommended where long heating cycles are required to make a brazed joint. Forms large fillets. Flux (3) (paste type) or flux (4) (powder type) recommended for use with this alloy.
	B4(c)	72	28	..	...	778	778	1422	1422	77.1	0.002–0.005	...	True eutectic composition of Cu and Ag. Very fluid above 778° C. (1422° F.). Medium temperature brazing alloy. Has no low-melting elements such as zinc or cadmium and therefore will stand elevated service temperatures for longer periods of time than other medium temperature silver alloy for brazing. Especially applicable for brazing in a reducing atmosphere without the use of a flux. This alloy cost more than alloys mentioned previously because of higher silver contents.
Special silver alloy filler metals	B5	35	26	21	18 Cd	608	702	1125	1295	...	0.003–0.008 for ferrous materials 0.003–0.010 for nonferrous materials	32,000 30,000	Lower silver content and lower-cost alloy than B1 or B4(a). Will make large fillets but shear strength is not as good as B1 or B4(a).
	B6	10	52	38	...	820	870	1508	1600	...	...	...	High temperature silver alloy for brazing. Used for applications where silver content should be low in order to prevent breaking of such materials as slightly stressed nichrome. B7 best for furnace brazing cast iron in a hydrogen atmosphere.
	B7	7	85	..	8 Sn	946	985	1735	1805	...	...	...	

* Critical temperatures—
m. p.—Melting point is a term which has been used indiscriminatly in the past. The m. p. in this article means solidus temperature. This is the highest temperature at which a particular alloy is completely solid.
f. p.—Flow point is again a term which has been used indiscriminately in the past. The f. p. in this article means liquidus temperature. This is the lowest temperature at which a particular alloy is completely liquid.

Notes in Connection with Table 2

(1) Shear strengths are based on brazing low-carbon steel to low-carbon steel. The maximum ultimate shear strength for design purposes is specified. Use a factor of safety.

(2) Recommended clearances are based on brazing low-carbon steel to low-carbon steel. For some cases two sets of joint clearances are recommended, one for ferrous materials and the other for nonferrous materials. This is done for the following reasons:

(A) Ferrous materials in general have a higher shear strength than nonferrous materials and therefore the smaller clearance range gives the higher shear strength required.

(B) Nonferrous materials in general have a lower shear strength than ferrous materials and a larger clearance range will give the needed strength.

(C) The brazing alloy tends to alloy more with nonferrous materials than ferrous materials and therefore has a retarding action on capillary attraction. Hence a larger clearance range is recommended when brazing nonferrous materials.

The clearance used, in many cases, may depend on the higher machining costs for small joint clearances and tolerances balanced against the cost of the brazing alloys for larger clearances and tolerances.

There are any number of fluxes which are commercially available. The following are some of the characteristics describing these fluxes:

(3) General-purpose, acid-fluoride, paste-type, corrosive flux. For use with low- and medium-temperature silver alloy filler metals.	Remove flux residues from the work immediately after brazing by washing in running water (preferably hot) aided by scrubbing with a wire brush.
(4) Acid - fluoride, powder-type, corrosive flux. Used with medium temperature silver alloy filler metals where the required heat input is too great for the use of (3) flux.	These fluoride fluxes will irritate the skin, nasal passages and eyes. Therefore proper ventilation and safety precautions should be taken when using these materials.

The uses of these brazing sheets are many, and are especially applicable to the brazing of small stamped or formed parts.

It will be well to note that at the present time there are only three practical methods of heating aluminum for brazing parts, namely, torch brazing, furnace brazing and flux bath brazing.

An anodized finish will vary in color depending on which brazing sheet is used. Filler metal surfaces on brazing sheet B, B-B, C and C-C will show up darker when anodized compared to base metal. This is due to the higher silicon content in the brazing alloy. The following table will give an idea as to the use which the brazing sheet can be put to after brazing.

Designation	*Approximate Tensile strengths of brazed joints, psi.*	*Use*
B and B-B	14,000 or over	General purpose—anodized finish on filler metal surfaces darker than on base metal—not heat treatable
C and C-C	24,000 or over by solution heat treatment 35,000 or over by solution heat treatment and Precipitation Heat treatment	General-purpose, high strength—anodized finish same as Nos. B and B-B—heat treatable

The best clearance for any given joint is best determined by trial. However, in general, the following clearances can be used.

Clearance, in.	*Length of lap, in.*
0.006–0.010	$^1/_4$ or less
0.010–0.025	Over $^1/_4$

Fluxes

Because of the limitations of this article only the characteristics of three types of fluxes, which are commercially available, will be discussed as follows:

Flux No. 1. This flux is the lowest melting of the three and is the general-purpose flux particularly at brazing temperature 1100° F. and below. Flux No. 1 is the most active chemically and it will produce the maximum flow of brazing alloy. Used for torch and furnace brazing.

Flux No. 2. This flux is somewhat higher melting and almost as active as No. 1. This is the lowest cost of the three fluxes. It is also a general-purpose flux, especially in applications when the brazing temperatures are above 1100° F. Used for furnace brazing only.

Flux No. 3. This flux is the least active chemically of the three brazing fluxes. Its fluxing action is almost entirely confined to the removal of oxide, leaving the metal surfaces practically unaltered. This is ideally suited for brazing assemblies having thin-walled components (less than 0.020 in.). It is good for applications where it is important to obtain smooth surfaces. This flux is generally used for brazing where the temperatures are above 1100° F.

These three fluxes come in the form of a powder. They are usually mixed with water to form a thick paste which can then be brushed on the joint.

In cases where the joint area of an assembly is confined and is to be furnace brazed it is a good idea to evaporate the water from the fluxed area. If this is not

done hydrogen gas may be formed and ignition of this hydrogen may be of sufficient violence to push the assemblies out of alignment. The formation of this gas can be prevented either by a preliminary drying operation or by mixing the powdered flux with either methyl or ethyl alcohol instead of water.

These fluxes are corrosive and should be washed off all parts after brazing. Hot running water should be used to dissolve aluminum brazing fluxes. Cleaning of these fluxes may be aided by the use of a wire brush: do not use wire brush too vigorously or it will scratch the aluminum surface.

D. Other Filler Metals and Alloys

The filler metals covered in this section are special and any applications where the use of these alloys are indicated should be analyzed from all angles as in many cases the equipment required to braze the parts would be special.

There are any number of special brazing alloys, a few of which are tabulated as follows:

Filler metal	**Critical temperature flow point* ° *C.*	° *F.*	*Remarks*
80 Ni, 20 Mn and other Ni-Mn composition	1275	2327	Used for high-temperature, high-strength applications on some stainless steels. A pure dry hydrogen atmosphere must be used.
85 Ag, 15 Mn	970	Approx. 1778	This alloy is a German development used during the war in Germany for joining austenitic steels which have high temperature applications. This alloy has high strength up to 850° F.
100 Ni	1452	2644	Used for joining such metals as tungsten and molybdenum for high temperature applications. Should be brazed in hydrogen atmosphere or in vacuum.
37.5 Au, 62.5 Cu	990	1814	The brazed joint has good mechanical properties. Has a flow point between that of copper and Cu-Ag eutectic. Most widespread use found in vacuum tube industries.
65–75 Ni, 13–20 Cr, 2.75–4.74 B, 10% max. {Fe, Si, C}	1094	2000	Commercially available filler metal used mainly with base metals with good high-temperature properties. Furnace brazing is usually used with a good reducing atmosphere such as dry hydrogen. Tests to date indicate this filler metal has good mechanical properties at high service temperatures.

* See footnote Table 2.

(*To be continued*)

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(*Continued from page 531*)

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Braze-Welding Furnace and Boiler Sections

by E. E. Cashen

BRAZE-WELDING of cast iron furnace and boiler sections is a standard operation. It might seem that furnace heat would melt a braze weld. Actually, water in sections near the fire keeps the temperature well below the weakening point. Other sections are too far away from intense heat to be affected.

However, this is a job that requires some skill and experience and the welding operator should practice on scrap sections. In this way the operator can experiment with tip sizes, amount of flux, methods of chipping and grinding, temperatures and other variable conditions. The metal around these practice welds can also be broken out with a hammer and examined to see whether a proper bond has been obtained.

GETTING READY TO WELD

In most cases the boiler should be dismantled. Then the branches of the cracks should be located. One way to do this is to clean off the scale and rub oil over the surface at the ends of the crack or branches. Then wipe off all excess oil and rub white chalk over the oiled surface adjacent to the crack. The oil will be absorbed by the chalk. Just beyond the end of each crack drill a small hole, about 1/4-in. in diameter, through the cast iron. This will prevent the crack from extending further when the part is heated.

Now the section should be cleaned and laid in welding position. Next, chip a shallow groove along the crack. But do not make the usual welding vee. A very light groove should be made only to aid in following the crack while welding. A thin layer of the bronze weld metal will stretch readily during the cooling and contraction, whereas a thicker layer would not. This would cause further cracking of the casting and cause the heavy bronze layer to pull loose a section of the cast iron next to the crack.

In addition, the metal on each side of the crack should be cleaned thoroughly with a wire brush or by light grinding to remove all grease or other dirt. The clean metal, including the cut, should extend to at least 1/2 in. on each side of the crack. Figure 1 shows the suggested shapes for the cut and cleaned metal.

E. E. Cashen is connected with Linde Air Products Co., a Division of Union Carbide and Carbon Corporation, Indianapolis, Ind.

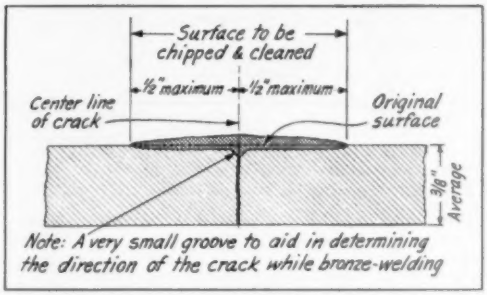

Surface to be chipped & cleaned
1/2" maximum
1/2" maximum
Center line of crack
Original surface
3/8" Average
Note: A very small groove to aid in determining the direction of the crack while bronze-welding

Fig. 1 This sketch shows a typical cross section of a braze weld on a boiler section

Now the part is ready for welding. Select a blowpipe welding tip that is about two sizes smaller than you would ordinarily use. This gives better control of the flame and permits you to use the least possible amount of heat. Now warm the entire section. Then concentrate the flame along the crack and heat it to a dull red heat. Heat the welding rod at the same time and dip it into bronze welding flux. Now melt some of the bronze rod on the heated area. The molten rod metal should spread smoothly and freely like water over a clean damp surface. This is tinning.

If the surface will not tin properly even though you have heated the part to the correct temperature and have used flux with the bronze welding rod, it probably means that the cast iron has been affected by the furnace fire.

In that case, prefluxing will be necessary. This can be done by dusting a very strong oxidizing agent, such as powdered potassium chlorate, on the part of the

Fig. 2 Chip out a narrow shallow groove. This only helps in following the crack while welding

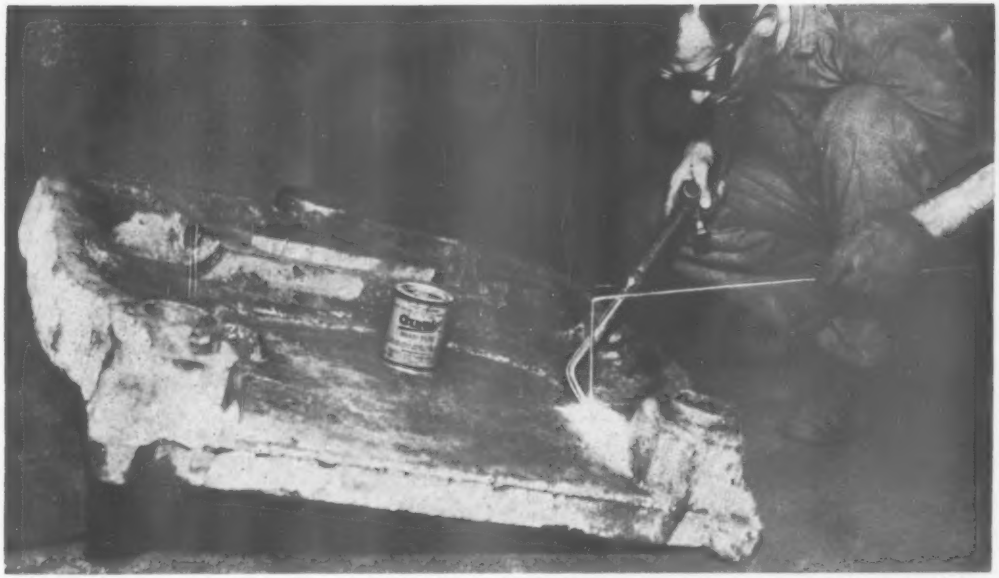


Fig. 3 If the crack ends at an edge or a corner, start welding at the center and move out toward the ends. Otherwise start at the branches of the crack and work to center

crack heated to a red color just ahead of the weld puddle. This material can be spread around and as soon as the foaming stops the regular tinning and braze welding will proceed easily and rapidly.

If the break extends into irregular sections of the casting or to edges or corners, start the weld at the center and move toward the end of the crack point. Otherwise, start welding the ends of the crack and work toward the middle. Small branch cracks should be welded working toward a central point.

Hold the rod and the flame approximately in line with the crack. Hold the blowpipe so that the flame preheats the metal just ahead of the molten puddle. Gradually move the puddle forward when the metal ahead of it is properly prepared. The bronze weld metal should extend for only $^1/_2$ in. on each side of the crack.

Keep the casting as cool as possible during welding. Deposit weld metal for about 2 or 3 in.; then stop and let the section cool slightly before you continue welding. This will cut expansion of the casting and the shrinkage stresses to a minimum.

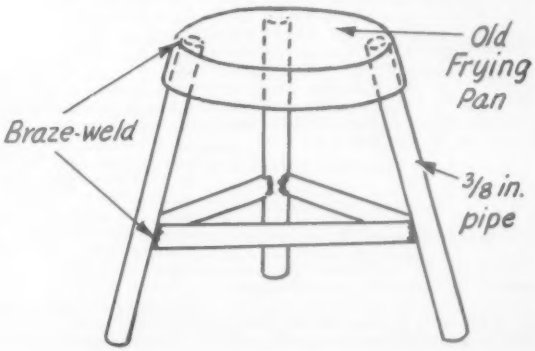
When the weld is completed the casting should be covered with asbestos paper, and permitted to cool slowly until it is cold. Be careful to keep drafts of cool air off the castings.

Milking Stool

by H. A. Thebom

YOU can make a comfortable milk stool from an old steel frying pan and $^3/_8$-in. pipe. Braze weld the rod legs and braces as shown in the sketch.

This is only one of many useful things for the shop, farm and home that can be made by the combination of braze welding and scrap pipe. Much pipe that has been discarded from piping systems is still ideal for stools, and other useful articles.



H. A. Thebom is connected with Linde Air Products Co., a Division of Union Carbide and Carbon Corp., Kansas City, Mo.

the AMERICAN WELDING SOCIETY

activities • related events

Nominations for Officers, Board and Nominating Committee Members

The Nominating Committee of the AMERICAN WELDING SOCIETY selected the following officers and directors for the term commencing October 1951:

President, C. H. Jennings, Westinghouse Electric Corp., Buffalo, N. Y.

First Vice-President, F. L. Plummer, Hammond Iron Works, Warren, Pa.

Second Vice-President, Eric R. Seabloom, Crane Co., Chicago, Ill.

Directors-at-Large: R. S. Green, Ohio State University, Columbus, Ohio; I. A. Oehler, American Welding & Manufacturing Co., Warren, Ohio; M. S. Shane, Cleveland Electric Illuminating Co., Cleveland, Ohio; E. O. Williams, Victor Equipment Co., Los Angeles, Calif.

The District Nominating Committees of the AMERICAN WELDING SOCIETY selected the following District Vice-Presidents and District Representatives on the 1951–52 National Nominating Committee:

District Vice-Presidents: No. 1 (New York and New England), E. N. Adams, American Institute of Steel Construction, Worcester, Mass.; *No. 3* (Southern), J. U. Durham, American Bureau of Shipping, Nashville, Tenn.; *No. 5* (Mid-Western), T. B. Jefferson, The Welding Engineer, Chicago, Ill.; *No. 7* (Western), A. P. Maradudin, Standard Oil Co., El Segundo, Calif.

District Representatives on 1951–52 National Nominating Committee: *No. 1* (New York and New England), E. F. Potter, General Electric Co., Schenectady, N. Y.; *No. 2* (Mid-Eastern), Q. E. Charlesworth, Bethlehem Steel Co., Bethlehem, Pa.; *No. 3* (Southern), J. F. Bryan, American Bureau of Shipping, Pascagoula, Miss.; *No. 4* (Central), R. S. Green, Ohio State University, Columbus, Ohio; *No. 5* (Mid-Western), J. D. Mattimore, Tube Turns, Inc., Louisville, Ky.; *No. 6* (Mid-Southern), A. K. Pandjiris, Pandjiris Weldment Co., St. Louis, Mo.; *No. 7* (Western), Harold P. Etter, Air Reduction Pacific Co., San Francisco, Calif.

Armed Service Members

At a meeting of the Finance Committee held on Mar. 30, 1951, with subsequent approval of the Executive Committee of the A.W.S. at a meeting held on Apr. 4, 1951, both Committees were in agreement that the SOCIETY establish a moratorium on dues of those of its members entering the armed services, in the enlisted grades, as well as a special subscription rate to THE WELDING JOURNAL during the period of their service with a guarantee of reinstatement in the SOCIETY after completion of service, providing they resume normal dues payment. Accordingly, the Finance Committee acted as follows:

1. That in the case of members who have joined or been inducted into the armed forces and who, because of this are unable to meet dues payment, upon request to the SOCIETY, the name of such members shall be continued on an "inactive" membership list for the duration of the war.

2. That in the case of members who have joined or been inducted into the enlisted grades of the armed forces and who because of this are unable to meet dues payment, upon application to the SOCIETY, such members can obtain THE WELDING JOURNAL during this period at a nominal annual fee of $3.00.

3. That this information be transmitted to the Sections and suitable notice published in THE WELDING JOURNAL, and perhaps repeated for two additional times, every other month.

Seventh Annual Convention National Welding Supply Assn.

The Seventh Annual Convention of the National Welding Supply Assn. was held at the Hotel Statler, Cleveland, Ohio, on May 7th, 8th and 9th. Over 200 dealers from California to New England were registered, many of them A.W.S. members and past and present section officers. The program provided excellent arrangements for presentation of important papers dealing with the problems of the supply companies, opportunities to get together with the manufacturers, entertainment and good will meetings.

The annual report highlights the difficulties created by M.P.A. orders and economic stabilization agencies. This report indicates that Zone Meetings held during the year were extremely popular and the benefits derived from standardized procedures in overhead calculations, taking care of credit applications and other items of a like nature. The newly elected officers for 1951 are:

President: R. S. McCracken, R. S. McCracken & Sons, Inc., Philadelphia, Pa.

Vice-Presidents: Eastern Zone—R. C. Waldie, Mgr., Welding Dept., Williams & Co., Inc., Pittsburgh, Pa. Southeastern Zone—W. A. Rice, President, Virginia Welding Supply Co., Charleston, W. Va. Southwestern Zone—C. O. Stilwell, Pr., Gulf Welding Equipment Co., New Orleans, La. Central Zone—R. P. Tarbell, President, Scott Tarbell, Inc., Cleveland, Ohio. West Central Zone—R. T. Rogers, President, R. & R. Welding Supply Co., Des Moines, Iowa. Western Zone—G. Milton Sims, Absco Welding Supplies, Los Angeles, Calif.

Directors: Term expires 1953—James C. Dawes, James C. Dawes Co., Martins Ferry, Ohio (to fill the unexpired term left by the vacancy of Mr. Tarbell's elevation to the Vice-Presidency). Terms to expire in 1954—J. A. Cunningham, President, J. A. Cunningham Equipment Co., Philadelphia, Pa.; L. P. Beaver, Jr., Beaver Welding Supply Co., Memphis, Tenn.; Allen H. Young, President, Independent Distrib. Co., St. Joseph, Mo.; L. J. Weisgerber, Mankato Welding Supply Co., Mankato, Minn.

J. F. Lincoln Speaker at 14th Tri-State Conference

J. F. Lincoln, President, Lincoln Electric Co., was the principal speaker at the 14th Tri-State Conference held in Pittsburgh on April 27th at the Hotel Webster Hall.

Mr. Lincoln traced the relationships and wide gaps between the "boss" and workingman through the ages and stated that unfortunately this gap still persisted in modern times at least in the mind of the average employee.

Mr. Lincoln held this gap, real or fancied, was not in the best interest of the working man, the employer, business in general or the country as a whole. Any feeling that the interests of the two were not identical resulted in lack of productive effort and the retardation of development of the best in the employee. Each of us possessed skills that were invaluable to the job we were doing. It was important to provide some incentive to bring out latent and hidden skills and capacities in each of us. If these could be developed to the limit of our capacities, the results would be truly remarkable. Often by accident or some unusual demand some such latent ability was brought to the surface and once this happened it marked a turning point in our

life or career. Industry should do its utmost and we ourselves should do our best to bring forth these latent skills and capabilities.

Mr. Lincoln pointed out that the most important asset of any successful company were the abilities and skills and the will to utilize them of the people that composed the company. Unless we were happy in our job we could not lead a happy life and actually would feel frustrated.

Mr. Lincoln stressed the human limitations in desiring to continue in the ways and methods of our youth. Progress can only be made if we always keep in mind that everything we now do will eventually and perhaps soon be superseded by something better.

The hesitancy to use welding on the part of some engineers was a manifestation of a desire to stick to the methods familiar to us in our youth. The excuse that a welded ship failed and, therefore, was not safe would be the same as trying to starve ourselves because of an experience of ptomaine poisoning. The ptomaine poisoning and the failure of a welded ship represented a specific combination of unfavorable circumstances.

Mr. Lincoln took occasion to poke a little fun at the Engineer who regarded his factor of safety of four as the "sacred cow." He reminded the audience that the job of the Engineer was to do well with $1.00 what any bungler could do with $2.00 after a fashion. Holding blindly to a factor of safety of four was not good engineering. As an example he cited the remarkable progress made of necessity in the aircraft industry through the use of a factor of safety of 1½. Actually this factor of safety of four might represent a potentially more dangerous condition than the use of a factor of safety of two or even less.

A.W.S. Brazing Groups Visit Delco-Remy

The A.W.S. Committee on Brazing and Soldering and the Subcommittee on Brazing Filler Metal of the Filler Metal Committee met in Anderson, Ind., on April 11th and 12th, in conjunction with an inspection trip of the brazing and welding operations of the Delco-Remy Division of General Motors Corp.

The inspection trip drew a record attendance at the meetings. After a three-hour tour of the plants and a splendid lunch in the Delco-Remy cafeteria, everyone who attended agreed that it was most worth while; witness the smiles and satisfied looks in the accompanying picture.

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175	325	650	1200	1750
188	338	700	1250	1800
200	350	750	1300	1850
213	363	800	1350	1900
225	375	850	1400	1950
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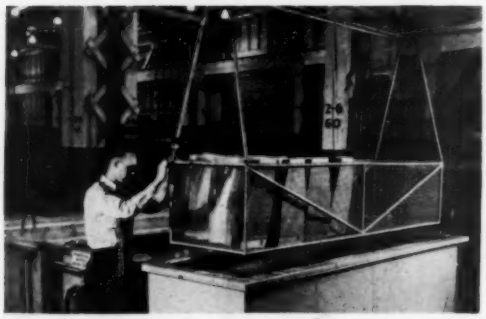
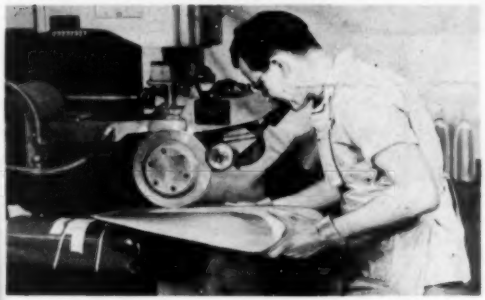


Naturally, the best surface preparation plus the best welding technique will produce the best spot welds. And, today, many aluminum fabricators are combining their excellent welding techniques with the Diversey Pre-Welding Treatment. Results are outstanding.



Users report improved quality of the welds, increased quantity of spot welds before tip cleaning is required and prolonged life of electrode tips. One user reported an increase of spot weld output of 50%. Another reported an increase of 4,000% in the number of spot welds made before electrode tips required redressing.

The Diversey Pre-Welding Treatment for aluminum incorporates the use of Diversey No. 36 to remove identification markings, grease, dirt, etc.; and the use of Diversey No. 514 to remove oxide, heat scale, and to produce minimum surface resistance. The Diversey Pre-Welding Treatment is easy, efficient, practical, and surprisingly economical to use. Complete information is available. Direct inquiries on your company letterhead to: The Diversey Corporation, Metal Industries Department, 1820 Roscoe Street, Chicago 13, Illinois. In Canada: The Diversey Corp. (Canada) Ltd., Lakeshore Road, Port Credit, Ontario.

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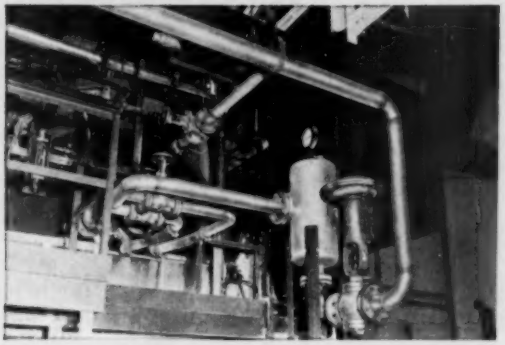
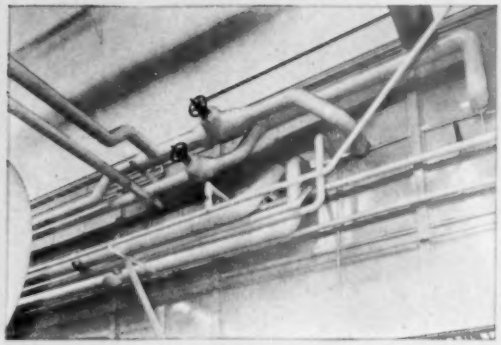
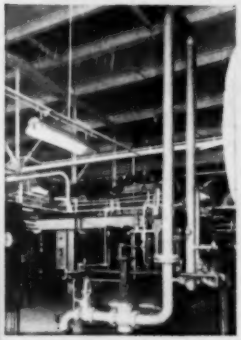
Penicillin processor welds stainless steel piping ½" and up



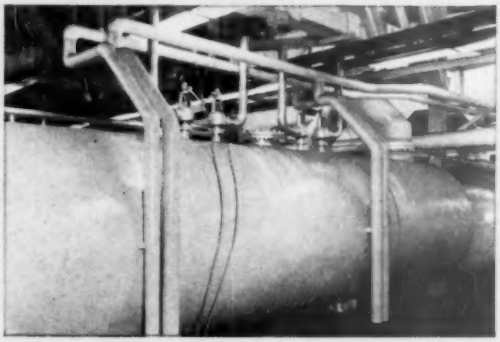
Advanced facilities in plants and laboratories help Eli Lilly and Co., Indianapolis, turn out a high volume of pharmaceuticals, biologicals, and antibiotics. This new filtration unit in the penicillin processing system uses 3" and 4" Type 316 stainless steel—chosen to resist corrosive action. Welded system with TUBE-TURN Welding Fittings and Flanges was chosen to provide maximum strength and eliminate leakage.



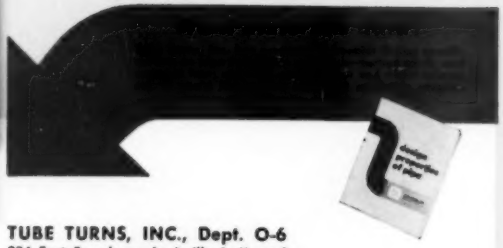
Neat appearance of insulated lines demonstrates simplicity of welded piping. Insulation was applied quickly over pipe and TUBE-TURN Welding Fittings, with no awkward joints to work around. Maintenance men know that insulation will last, with no leakage to cause deterioration. Cleanliness and neatness are prime requirements in Eli Lilly plants.



Up in the air goes a loop welded with 6" pipe, joined with TUBE-TURN Welding Fittings and Flanges. Structural strength here is a must. In this fermentation tank where life-saving penicillin is made, tiny lines of ½", as well as larger sizes, are welded. Comparable modern facilities are provided for making streptomycin and other products.



Lines to process vessel fit neatly into a small space when TUBE-TURN Welding Elbows make the turns. Eli Lilly engineers specified process piping for optimum flow conditions, compactness, and elimination of leakage.



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Photograph taken at the head table at the opening luncheon of the American Welding Society the first day of the Western Metals Congress and Exposition held in Oakland, California, March 19–23, 1951. Left to right: Charles Smith, H. E. Rockefeller, Harry Kennedy, J. C. Magrath, AWS Secretary, E. A. Daniels, Richard Labagh, Prof. Gilbert Schaller, Ted Jefferson, LaMotte Grover, and Edward Bartz.

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WHO A!
STOP RIGHT THERE — I KNOW ALL ABOUT THIS CHAMPION BLUE DEVIL... WENT UP TWENTY FLOORS USING CHAMPION BLUE DEVIL WITHOUT A HITCH... GOT TWO DAYS AHEAD OF SCHEDULE — AFTER ALL EVERY WELDER KNOWS...
... FOR DEPENDABLE WELDS ON BUILDING CONSTRUCTIONS WE ALWAYS STANDARDIZE ON CHAMPION!!
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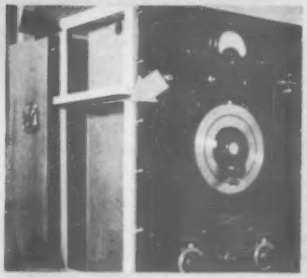

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NEWS OF THE INDUSTRY

University of Florida Second Annual Structural Engineering Conference

William Spraragen, Director of the Welding Research Council (also Editor, THE WELDING JOURNAL), upon invitation, attended the Second Annual Structural Engineering Conference sponsored by the Civil Engineering Department of the University of Florida on March 16th and 17th, at Gainesville, Fla.

The objective of this Conference was to bring together engineers and architects interested in structural engineering, and to provide for an exchange of ideas and information on materials and methods of construction. The Planning Committee consisted of representatives of the AMERICAN WELDING SOCIETY, the American Society for Civil Engineers, the Florida Engineering Society, the American Concrete Institute, the American Institute of Steel Construction, the Portland Cement Association, the Florida State Road Department, the Structural Engineers Council of Jacksonville and, of course, the Civil Engineering Department of the University of Florida. Approximately 450 people attended the Conference, equally divided between practicing engineers and students.

Two subjects were selected, one dealing with various phases of welding and the other with prestressed concrete. The papers on welding included the following: "Design of Welded Joints," by LaMotte Grover, Air Reduction Co., New York, N. Y.; "The Work of the Welding Research Council," by W. Spraragen, Director of the Welding Research Council, New York, N. Y., and "Shop and Field Practices in Welding," by R. W. Cloues, Aetna Steel Co., Jacksonville, Fla.

In his talk Mr. Spraragen covered briefly the history of the Council, the organizational setup, its objectives, methods of operation and publications, and then devoted his attention to five current projects under the Structural Steel Committee, namely, the Box Girder Flexural Tests, the Lehigh Rigid Frame Research Program, the Columbia Impact Testing Program of Beams, the M.I.T. Investigations on Stability of Welded Structures in Compression and the Florida University Program on Cover Plates of Welded Girders. Mention was also made of proposed work on improving the behavior of welded structural joints under cyclic loading. Reference was also given to other projects of the Council and how this work tied in with the Code-writing activities of the AMERICAN WELDING SOCIETY.

The Director took occasion to visit the laboratories of the University of Florida where the Structural Steel Committee's investigation is in progress on Transfer of Stresses from Cover Plates and Flange Sections of Beams.

G-E Welding Divisions Announce Personnel Changes

A. F. Vinson, manager of General Electric's Welding Divisions at Fitchburg, Mass., has temporarily relinquished his duties in order to attend the Advanced Management Program's Business Training Course at the Harvard Graduate School of Business Administration.

To assume Mr. Vinson's responsibilities during his absence, R. C. Freeman has been named acting manager of the Welding Division, according to an announcement by N. M. DuChemin, general manager of the G-E Small Apparatus Divisions.

A native of Plainfield, Ill., Mr. Vinson was graduated from Michigan State College in 1929 with a B.S. degree in electrical engineering. He joined G-E later that year on the company's Test Course at Fort Wayne, Ind. Following successive positions as process engineer, direct-current motor section head, and inventory control supervisor, he was named assistant production manager at Fort Wayne, a position he held from 1939 to 1945.

Mr. Vinson then moved to Schenectady, N. Y., to become assistant production manager of the G-E Apparatus Department. He was appointed chairman of the committee in charge of the former Welding Equipment divisions in 1947, and manager of the Welding Divisions a year later.

Graduated from the University of Minnesota in 1929, Mr. Freeman joined G-E the same year on the Test Course at Schenectady. Shortly thereafter he was transferred to the Lynn, Mass., plant and was assigned to the Motor Engineering Division. In 1936 he went to the Welding Section and in 1946 assumed the post of division engineer of direct-current welders at Fitchburg. Mr. Freeman was named manager of engineering for the Welding Divisions two years later, and has held that position until the present.

B.W.R.A. Welding Summer School

The British Welding Research Association, 29 Park Crescent, London, W.1, held a Summer School in "Welding Design and Engineering" from Friday, May 25th to Saturday, June 2, 1951, inclusive. The purpose was to acquaint the practical man with up-to-date welding developments, to stimulate the application in industry of experimental knowledge and experience and to describe the present state of knowledge relating to some of the fundamental welding problems.

The course consisted of two introductory days during which recent developments in welding practice and metallurgical aspects of welding ferrous and nonferrous metals was discussed. After this there were five and a half days devoted to general lectures, commencing with morning sessions on welding problems such as Welded Structures Under Fatigue Loading, The Problem of Brittle Fracture and, Residual Stresses in Welded Structures, etc.

These were followed in the afternoons by specialized lectures comprising the following four main groups: Structures, Pressure Vessels, Ships and General Engineering and Machinery.

There were evening discussions on general topics of importance to welding engineers, such as: Fields of Application of Welding, Weldability, Distortion, and Factors Retarding the Application of Welding to Engineering Constructions.

Mt. Sinai Hospital

THE WELDING JOURNAL has learned that the structural welding for the above hospital as reported in our April issue was performed by the Craftsmen Welder, Inc., Brooklyn, N. Y.

We believe our readers will be interested in this information.

The greatest advancement in welding torch design and construction was made when NATIONAL engineers developed and patented the better way of making an effective, leakproof, damage proof joint between mixer and welding torch head; between cutting attachment and torch butt.

These neoprene sealing rings have taken the trouble out of the welding torch—they eliminated the use of a wrench to keep a tight seat. No other seating arrangement has given so much satisfaction over so long a time period. IT'S THE SEALING RING WHICH SAVES YOU MONEY — WHICH MAKES YOUR WELDING TORCH AND CUTTING ATTACHMENT STAY ON THE JOB LONGER — AND IT IS A PATENTED FEATURE OF NATIONAL WELDING EQUIPMENT CO.

Made by National SINCE 1910 WELDING EQUIPMENT CO., San Francisco 5, California

Protecting Concrete Piles

When the existing shells on the concrete piles of the Bellamy River bridge showed serious deterioration, engineers of the New Hampshire Department of Public Works and Highways decided to replace them with wrought iron shells. The former shells were rectangular in cross section, made up of two pieces bolted together. The new wrought iron shells were made circular in cross section, providing less resistance to tidal flow and avoiding high internal stresses which would have existed at the corners of a rectangular cross section. The new shells were made by bending ½-in. plate and welding it longitudinally, and were back-filled with concrete. The axis of the two welded seams was placed transversely to the direction of flow, in the belief that the presentation of a smooth surface on both upstream and downstream faces of the piles would help to extend the life of the plate, particularly at or near the weld metal, by reducing the tendency toward cavitation. Some indication of the severe conditions to which these piers are subjected is given in this photograph, in which tidal range is marked by marine deposits appearing as white lines on the tubular sections. The photograph was taken near low tide.

Engineering, Marine and Welding Exhibition

The Exhibition once again will be the biggest display of engineering manufactures in the world and will be held at Olympia, London, from Aug. 30 to Sept. 13, 1951. The Exhibition will be open during the Festival of Britain celebrations. A record number of overseas visitors is expected.

Employment Service Bulletin

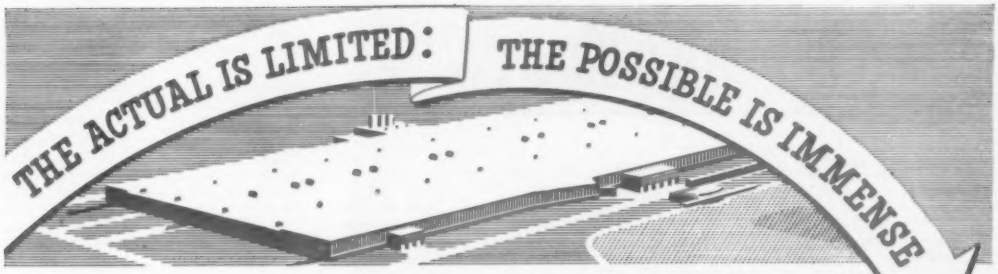
Services Available

A-616. Position wanted in top-level supervision. Fifteen years' experience in design, sales, field work and fabrication of boilers, pressure vessels and weldments. Good personality and educational background. Married, age 36, active athlete. Employed as welding superintendent.

A-617. Technical Sales Manager of British electrode manufacturing company desires situation in U.S.A. offering greater scope and freedom from controls and restrictions. Full evidence of sales record and technical experience available.

National
Carbide
IN THE RED DRUM
EFFICIENT
ECONOMICAL
DEPENDABLE

FOR WELDING and CUTTING
Use National Carbide in the Red Drum
Write us for information as to nearest available stock.
60 E. 42nd St. NATIONAL CARBIDE COMPANY New York 17, N.Y.
A Division of Air Reduction Co., Inc.



NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

© LE Co. 1951

FLEXIBILITY IN MANUFACTURE MEANS LOWEST COST PER PIECE

Products designed to utilize the economies of welded steel can be manufactured at lower cost regardless of quantity produced. Any product design can be developed from an unlimited combination of steel shapes to suit the type of manufacturing equipment available.

Each of the tee sections shown has been designed to withstand equivalent loads. As quantities of production increase and brakes, shears and forming equipment become advisable, less material is, of course, required and the amount of welding itself can be reduced.

Your Lincoln Welding Engineer will gladly explain how your products can be simplified and fabricated at lower cost using welded steel construction. Simply write The Lincoln Electric Company, Cleveland 1, Ohio.

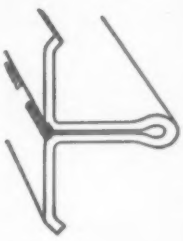


Fig. 3. Angles, brake formed from plate, have better dimensions to withstand loading. Section requires only light, intermittent welds. Costs 50% less than Figure 1.

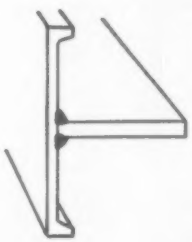


Fig. 4. Tee section fabricated from light channel is automatic Lincoln-welded to plate cut to shape by high-speed equipment. Gives better material distribution. Costs 35% less than Fig. 1.

Fig. 5. For higher quantity production, tee can be brake formed as a single piece from sheet and automatically Lincoln-welded at top. Weighs 30% less than Figure 1 . . . costs 40% less.

the ACTUAL

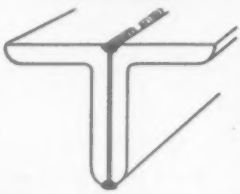


Fig. 1. Tee section *fabricated in small lots by welding standard angles back to back. Requires only hack saw and welder.*

increasing the YIELD

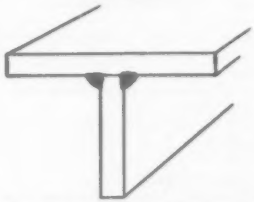


Fig. 2. Tee section *for medium quantity lots for the shop having shear or flame cutting equipment. Costs 25% less than Figure 1.*

the IMMENSITY of the POSSIBLE

Economical production regardless of quantity

SEE HOW WELDED STEEL IS FABRICATED AT LOW COST

Machine Design Sheets free on request to designers and engineers. Write on your letterhead to Dept. 96,

THE LINCOLN ELECTRIC COMPANY

CLEVELAND 1, OHIO

NEW PRODUCTS

Cast Iron Welding Flux

A new cast-iron welding flux under an old name has just been announced by All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y.

The new flux takes the place of and the name of the former All-State No. 1 Brazaloy Flux. It is a different compound of more finely ground powders and, from its inception, has demonstrated better cleaning action than any of its predecessors. It imparts superior flow characteristics to cast-iron welding rods.

Improved No. 1 Brazaloy Flux has been developed particularly for use with All-State No. 1 Cast Iron Welding Rod and All-State No. 3 Cast Iron (copper-coated) Welding and Brazing Rod and it can be used with rods of other manufacturers.

Heavy Duty Radiagraph

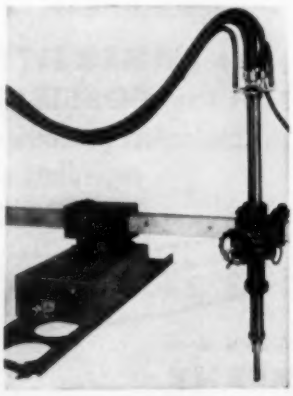
The new Airco No. 41 Radiagraph, a motor-driven straight track-guided machine, perfect for shop and mill jobs which require a travelling carriage to carry equipment past the work, has been announced by Air Reduction Sales Co., a Division of Air Reduction Co., Inc.

This new machine will greatly simplify gas-cutting, flame-hardening and welding operations. It is extremely useful in steel mills for billet nicking, slab ripping and skull cutting. Its accuracy and wide speed range make it invaluable in maintenance shops where flame hardening is used extensively.

The smoothly machined top ensures solid and level mounting of equipment. Provisions are made for mounting the new Airco Plate Edge Preparation Device, the Universal Motorized Torch Arm and Holder Assembly and the Manual Torch Arm and Holder Assembly (illustrated). Also, automatic welding units such as the Airco Automatic Heliweld Head and the Aircomatic[R] Head, which in most cases require a carriage-type machine, can be readily mounted on this new Radiagraph.

Salient features include all-welded construction; accessible, self-contained electric panel; conveniently located controls; insulated bottom plate to protect internal parts from heat; speed ranges from 1 to 72 in. per minute with standard gear reduction unit (other speed ranges with special gear reduction units); and indexed speed control for manual selection of desired speeds.

To obtain Form ADC 670 containing further information about this new Radiagraph, write to the Airco sales office nearest you or to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.



Heavy Duty Radiagraph

Pennsylvania Optical Co. Will Put Its Own Trade Mark on Industrial Lens

The Pennsylvania Optical Co., one of the country's oldest optical goods manufacturers, recently announced it was introducing a complete line of industrial lenses under its own trademark. For more than 45 years the company has manufactured precision ground and polished optical products, including welding lenses made for other trademarks. Now for the first time it will label each lens with Penoptic, according to Henry Cheatham, vice-president.

"Our industrial line includes lenses for goggles and helmets," Mr. Cheatham said. "For more than 25 years we have manufactured individually polished lenses which we have supplied to head and eye protective equipment manufacturers. But we have never, until now, sold them direct to industrial consumers under our own brand name."

The new Penoptic welding lenses are packed individually in special envelopes and shipped in strong containers. Careful packaging eliminates breakage and the formation of the familiar factory film on the lens surface. It makes them easy to store with simple identifying code marks on each envelope.

"The reputation we have earned through years in the optical industry is back of this new industrial line," Mr. Cheatham said.

New Super Rustfree Steels

Uniworld Research Corporation of America, Cleveland, Ohio, announces a new series of electro steel alloys with the following features:

High yield strength: tensile strength ratio of 75,100: 95,300 psi. in the hot-rolled, fully annealed condition as compared with standard austenitic stainless steels which have a yield strength: tensile strength ratio of about 40,000: 80,000 psi.

High ductility: The alloy has an elongation of 49% and a reduction in area of 64.5% in the fully annealed condition.

High tensile strength at elevated temperatures: All tensile values are higher than those of Stainless 25–12, 18–8 Mo, 18–10 Ti and 18–10 Cb.

Improved corrosion resistance especially against different concentrations of sulphuric acid. Generally speaking, SR Steel alloys range in the "A" classification when exposed to these solutions at room temperature and in the "B" classification when exposed to these solutions at elevated temperatures.

SR Steels enable considerable savings in critical materials as they do not contain cobalt, columbium, titanium, zirconium and, in additionl use considerably less nickel than alloys of competitive performance.

All Super Rustfree Steel Alloys are weldable and some types can be used as filler material and are applicable not only to fusion welding as now practiced but also to "Weldbrazing," Uniworld's new method of joining and building up materials.

Diesel-Powered Lift Truck

A new industrial fork lift truck, powered by a Diesel engine and equipped with a hydraulic transmission was announced recently by the Philadelphia Division, Yale & Towne Mfg. Co. Called the "Diesel-Lift," this new truck is specifically designed for applications where fire hazards exist, where there is a limited amount of fresh air and in outdoor areas where continuous heavy-duty operation is a necessity.

Structurally, the Yale Diesel-Lift is built of pressed plate and bar steel, formed to shape, and electrically welded into a unit structure. Upright channels

Lift Truck

are cold-drawn and hot-rolled, special 6-in. heavy flange sections. The elevating fork carriage and telescopic channels are carried on bearings.

A long wheel base and especially wide wheel treads provide the stability and mobility required to handle heavy loads over rough yards. The steering wheel axle is pivoted to the truck frame providing articulation for ground level variations. Chassis clearance is over 9 in., sufficient for all but the most uneven terrain.

All undercarriage operating and steering connections are cadmium plated against corrosion. The tires—especially designed for the truck—have flat sidewalls to minimize bruising and failure where it most often occurs.

Heliarc Welding Used for Milk Container

An inside seam on a stainless steel container is being welded with a Heliarc welding torch. The container, which is 18 ft. high, will hold 2750 gal. of milk when completed by American Boiler Works of Everett, Wash. With the exception of the standard steel pipe-cooling coils, stainless

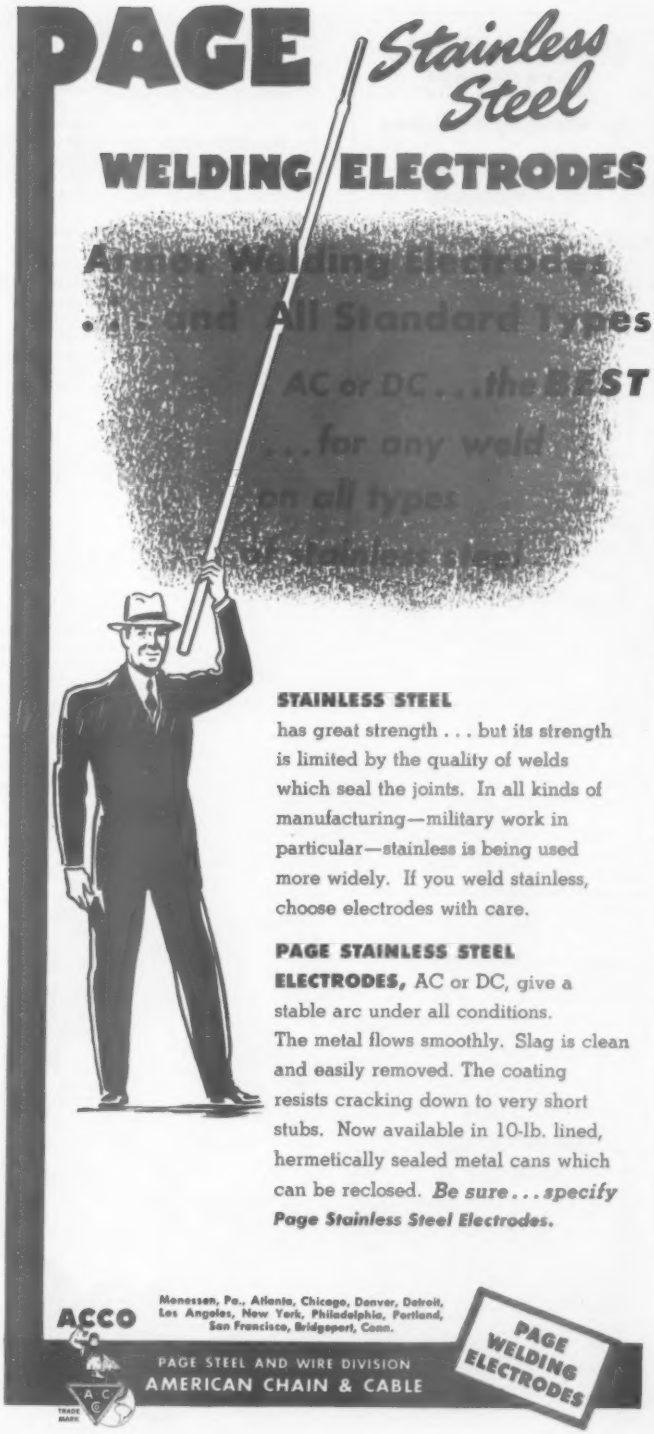
steel is used throughout the milk tank because it will not affect the purity of the product. Heliarc welding is used because it makes smooth, spatter-free welds in which there are no tiny pockets to catch food particles and aid in the formation of bacteria.

Silver Solder

A new silver solder characterized by excellent corrosion resistance and an unusually narrow plastic range has just been announced by Bent Laune, President, All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y.

This alloy was developed especially for broad application in the food industry. It is recommended for all kinds of food-handling equipment. Being cadmium-free, and cadmium being one of the most critical of the metals, the new alloy will be more readily available than silver solders containing cadmium and will find wide use in many industrial applications.

The new alloy is identified as All-State No. 155 Premium Silver Brazing Rod. It is 55% silver and has a low working temperature of 1155° F. It develops a tensile strength of 50,000 psi.


PAGE
Stainless Steel
WELDING ELECTRODES
AC or DC . . . the BEST
. . . for any weld
on all types
STAINLESS STEEL
has great strength . . . but its strength is limited by the quality of welds which seal the joints. In all kinds of manufacturing—military work in particular—stainless is being used more widely. If you weld stainless, choose electrodes with care.
PAGE STAINLESS STEEL ELECTRODES, AC or DC, give a stable arc under all conditions. The metal flows smoothly. Slag is clean and easily removed. The coating resists cracking down to very short stubs. Now available in 10-lb. lined, hermetically sealed metal cans which can be reclosed. Be sure . . . specify Page Stainless Steel Electrodes.
ACCO
Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.
PAGE STEEL AND WIRE DIVISION
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TWECO TERMINAL CONNECTORS

for Welding Machines

Bolt directly to positive and negative welder studs. Provide easy cable switch to reverse polarity. Simple cable disconnect for quick "Jump-In" of additional cable.

3 Sizes for cables #6 through 4/0

The male plug of TWECO "Sol-Con" and "Mec-Con" Cable Connectors connect with TWECO Terminal Connectors. Sol-Con and Mec-Con Cable Connectors are COMPANION ITEMS.

Write for Twecolog #8 giving data and prices on the complete TWECO line of electrode holders, ground clamps and cable connections for electric welding.

See Your Welding Supply Distributor

TWECO PRODUCTS

Tweco PRODUCTS COMPANY

BOSTON at MOSLEY

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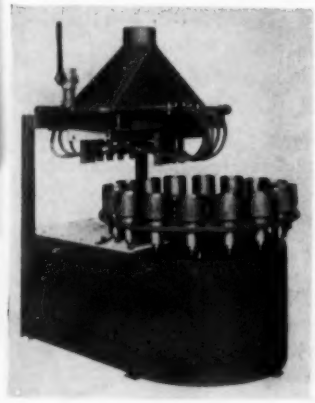
High-Speed Heating Unit for Brazing

A new, gas-fired production heating machine has been introduced by Gas Appliance Service, Inc., Chicago. This high-speed heating unit is ideally suited for two types of operations: (1) brazing plugs or adapters into ends of shell type units; and (2) annealing mouths of shell cartridges.



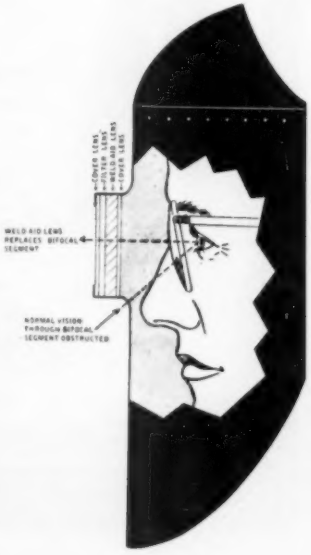
The heating zone in this unit consists of two rows of high-speed zig-zag burners. These burners, with their high rate of heat output, bring the sections to be brazed or annealed to the proper temperature in a minimum time—providing high production rates. This machine confines the heat to the work area and eliminates the usual excessive heating of surrounding portions. Cups which hold pieces are provided with spindles which rotate while passing through the heating zone.

The manufacturer claims production of 600 pieces per hour in a 60-in. diameter unit. Only one operator is required for loading and unloading pieces on this simple, easy-to-run machine. Other types and sizes of turntables or conveyor units are available for accommodating various diameters and production requirements. The gas-air mixture for the burners is supplied by a Furkert Gas/Air-mixer (made by Gas Appliance Service, Inc.)

Further information and prices on this and other localized heating units may be obtained by writing W. A. Pyhrr, Gas Appliance Service, Inc., 1211 Webster Ave., Chicago 14, Ill.

Optical Aid for Welders

Dr. Ellis L. Rabben, Industrial Optometrist, of Norfolk, Va., has developed, in conjunction with Willson Products, Inc., Reading, Pa., an optical aid for welders who wear bifocal glasses. The device, manufactured and marketed by Willson under the trade name "Weld-Aid Lens," is designed to help operators who depend on bifocal glasses for near vision. Since the vision slit of the welding helmet is placed for looking straight ahead, it does not permit use of the bifocal segment and welders who wear this type of glasses frequently suffer blurred vision, eyestrain and headaches which seriously reduce their productivity and skill. Thus, by the time many welders have accumulated considerable experience, they find it increasingly difficult to work at their trade because they cannot see well.



The Willson Weld-Aid Lens corrects this condition by supplying clear and unobstructed near vision over the entire area of the window in the helmet, thus replacing the unusable segment power of the welder's prescription glasses. The lens consists of high-grade optical glass accurately ground to a specific power and mounted securely in a durable plastic frame which fits easily into the average welding helmet. It is available in two sizes, $2 \times 4^1/_4$ in. and $2 \times 4^1/_4$ in. and in five powers: 0.75, 1.00, 1.25, 1.50 and 1.75. Complete instructions are furnished with each lens. To protect the Weld-Aid from front and rear pitting, it is recommended that it be placed between the cover and filter lenses.

Unionmelt Portable Manual Welder

A new portable semiautomatic manual machine for Unionmelt welding short seams is announced by Linde Air Products Co., a Division of Union Carbide and Carbon Corp. The new welding machine, the UWM-1, can be used on work which cannot be welded conveniently with fully automatic machines. It is also useful in small shops which have no automatic welding machines, yet have occasional need for the labor saving and quality advantages of Unionmelt welding.

The parts of the UWM-1, which include the welding head, a voltage control box and a 75-lb. capacity spoke-type rod reel, are mounted on a small steel chassis equipped with casters, and a lifting eye. A 17-ft. flexible hose connects the hand unit to the welding head. A lightweight hopper, that holds 3 lb. of the granular welding composition, is part of the hand unit.

Easy operation and low maintenance costs are obtained with the UWM-1 because its low-voltage rod feed motor and the series-type motor voltage control have few parts and require minimum adjustment. The control automatically maintains constant welding voltage even

Fig. 1 The Unionmelt portable hand welder

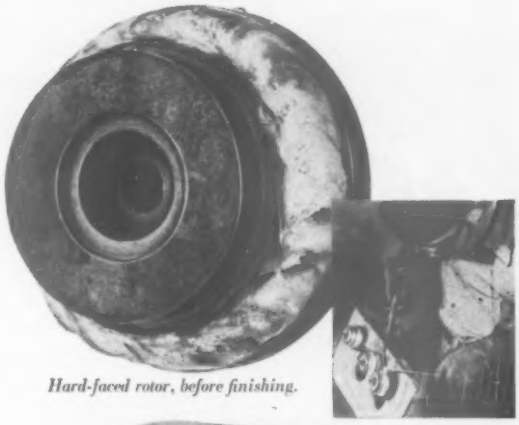
DOUBLES LIFE OF MIXER PARTS

...tough base metal withstands SHOCK
...hard-faced surfaces resist ABRASION and CORROSION

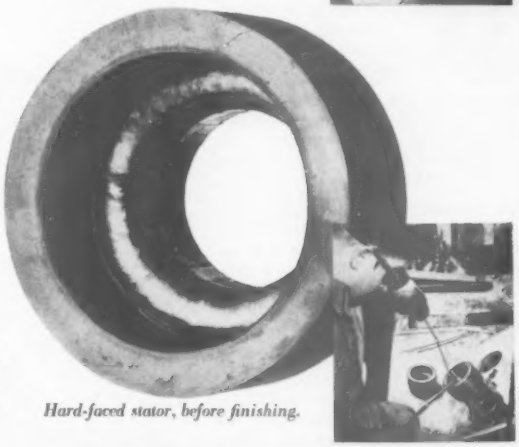
Here is another example of how hard-facing eliminates the need for a compromise when both hardness and toughness are needed for a particular part. This rotor and stator for a homogenizing machine are made from a tough base metal—Type 303 stainless steel. The bearing surfaces of the two parts are hard-faced with HAYNES STELLITE cobalt-base alloy. The parts are tough enough to stand up under the shock of pulverizing operations at high speeds . . . and yet the working surfaces are hard enough to resist the abrasive and corrosive effects of the materials being mixed.

For two years, no machine equipped with hard-faced parts has been returned or serviced because of rotor or stator failure. The heat-treated parts formerly used on these machines failed after only a year's service. The heat-treatment affected the corrosion resistance of the metal and also made the blades on the rotor too brittle.

For the whole story on hard-facing, including detailed procedures for applying various HAYNES alloys to wearing surfaces, write for the new 40-page booklet, "HAYNES Alloys—Hard-Facing Manual."



Hard-faced rotor, before finishing.



Hard-faced stator, before finishing.

Hard-facing doubles the life of these mixing-machine parts. In operation, they run with very close clearance at speeds of at least 3600 revolutions per minute. The clearance between the hard-faced bearing surfaces is filled in with the abrasive mixture.

HAYNES alloys

TRADE-MARK

"Haynes" and "Haynes Stellite" are trade-marks of Union Carbide and Carbon Corporation.

Haynes Stellite Company
A Division of
Union Carbide and Carbon Corporation
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General Offices and Works, Kokomo, Indiana
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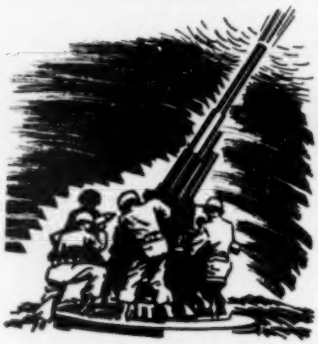
War production machinery takes a lot of maintenance

ALL-STATE No. 11 Nickel-Silver Brazing Rod



This most versatile of all All-State alloys makes strong dependable joints in 14 metals and any combination of them. Because each of these different kinds is used importantly by the Arsenals of America, there is no definable end to the applications of No. 11 in the defense establishment.

Nowadays, with war material dominating industrial activity, those without defense orders frequently have to wait for All-State No. 11. Critical nickel is a basic ingredient of this rod.

No. 11 melts at 1660° F. and flows at 1750°. Makes neat welds. *Fully machinable through the line of fusion.* It is stronger than mild steel in small fillet and beveled butt joints—85,000 psi. tensile, 160,000 psi. shear.

For complete details ask for new All-State 32-page booklet. This is a Buyers Guide to the complete line of ALL-STATE Alloys and Fluxes for Welding, Brazing, Soldering, Cutting and Tinning. Any A-S distributor can give you one.

A-S DISTRIBUTORS EVERYWHERE

ALL-STATE

WELDING ALLOYS CO., INC.

White Plains, N. Y.

though the welding operator does not hold the hand unit at a uniform distance from the work.

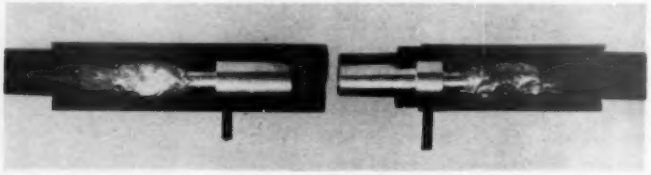
Welding with the UWM-1 is so easy that the operator needs no special training. Once the machine is set up for welding, any slight adjustments in welding conditions can be made from the control panel. The welding operation starts when the rod is scratched on the workpiece, and stops when the rod is lifted away. The UWM-1 is made for a. c. and d. c. welding.

Quick Connector

The Quick Connector male and female ends are attached to their respective sections of cable by the Cadweld Process. Copper oxide and aluminum are dumped into a graphite crucible and ignited with a spark. The reduction of copper oxide by the aluminum produces molten copper which flows over the quick connector end and the cable welding them together.

Current contact is made by positive wedging action: (a) No springs, (b) no pins, (c) no cams.

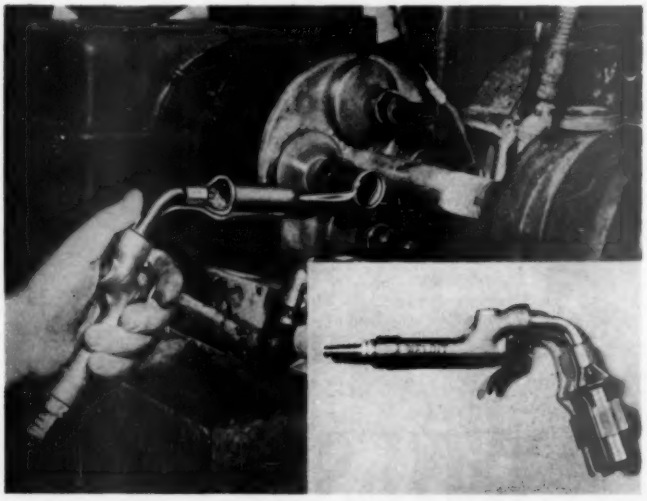
Write for *Bulletin No. 413* today to the Erico Products, Inc., Cleveland 3, Ohio.



Quick Connector

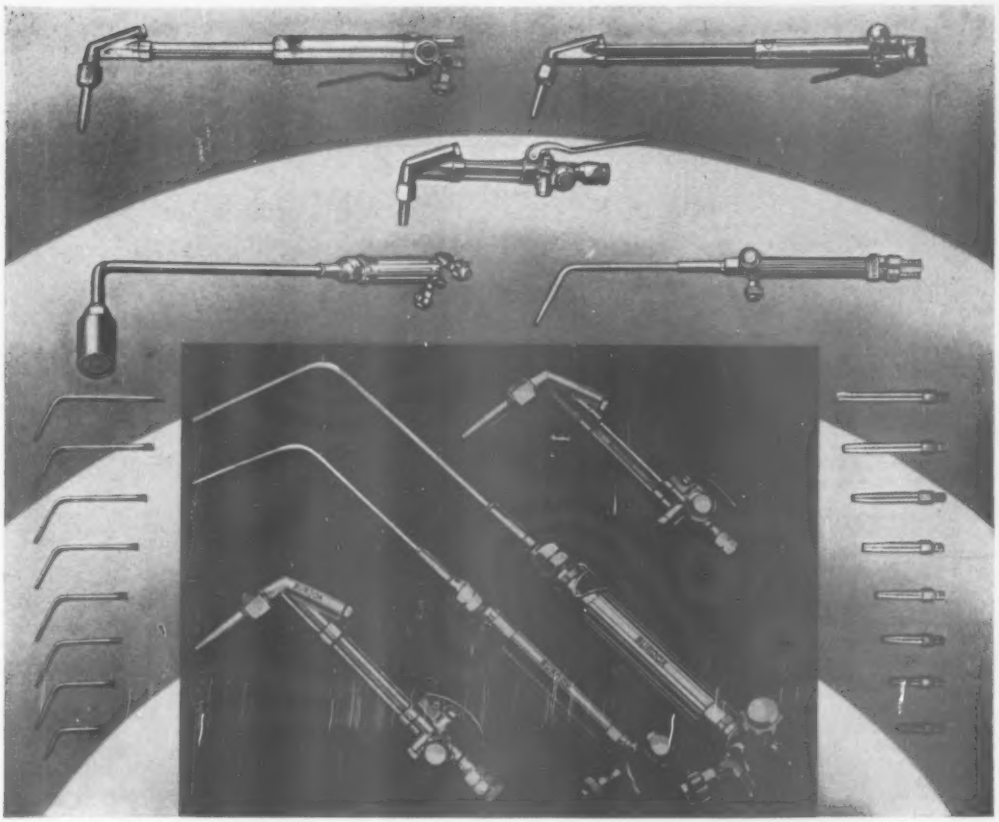
New Torch for Camera and Optical Lens Work

A new Weldimatic torch, manufactured by Weldit, Inc., Detroit, Mich. Originally this torch was especially designed for Argus, Inc., of Ann Arbor, Mich., manufacturers of cameras and optical instruments. The torch is employed in melting the adhesive which attaches camera lens to a spindle on a grinder. It does a better job faster than old methods, with greater economy of both time and fuel. It proved so successful that Weldit, Inc., has placed it in production. The torch is fueled with either natural or propane gases.



New Torch for Camera and Optical Lens Work

WEAR YOUR AWS EMBLEM



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abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,545,309—Weld Testing Instrument—Rex S. Roberts, Belmont, Mass., assignor to Transducer Corp., Boston, Mass., a corporation of Delaware.

A weld-testing instrument comprising an electromechanical transducer, and means providing a sonic column for coupling this transducer to a weld plate at one side of a weld is provided in the patent. An electromechanical receiver also forms a part of the instrument and means provide a sonic column coupling the receiver to the weld in the plate at the said one side thereof. A high-frequency oscillator connects to the transducer and means connect to the receiver for indicating the intensity of the energy reflected by the weld with the axis of the second-mentioned sonic column extending through the weld perpendicularly to the surface of the plate. The axis of the first-mentioned sonic column is arranged at an angle slightly less than the critical angle at which the refraction causes the energy generated by the transducer to proceed longitudinally through the plate toward the weld.

2,545,998—Welding Current Regulator—Edward C. Hartwig, Towanda, N. Y., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

Hartwig's current regulator includes apparatus for supplying a load intermittently from a source comprising coupling means to be applied to the load for deriving power only when the load is supplied. A first means connected to the coupling for deriving a first potential of substantially constant magnitude, a second means connected to the coupling for deriving a second potential which is proportional to the load current, and third means to be connected between the first and second means and the load. The third means controls the current flow through the load in accordance with the relationship between the first and second potentials.

2,546,458—Work Holder for Use in Welding—Ernie L. Launder, Montebello, Calif., assignor to H. and L. Tooth Co., Los Angeles, Calif., a corporation of California.

This patent is on a specialized work holder for use in welding operations and includes a stationary base that has a C-shaped frame pivotally carried on the base. The position of the frame on the base is controlled by a specialized control means of the apparatus.

2,546,942—Welder's Helmet—Joseph Doran, St. Louis, Mo., assignor to Joseph J. Doran, Barrington, Ill.

Doran's welder's helmet includes a head hood provided with a panel normally closing the sight opening through the hood. A specialized type of a means is provided for opening the sight opening through the hood, and chin operated means are provided in the helmet for actuating or controlling the sight opening control means.

2,547,320—Radius Guide for Cutting Torches—Herbert S. Hedley, Banning, Calif.

This patented cutting-torch guide comprises a spider having a centering rod axially mounted thereon. A carrier arm is axially adjustable and rotatably mounted on the centering rod of the spider. A sealed radius rod is adjustably mounted on the carrier arm and a socket member is adjustably mounted on the radius rod to hold a cutter-torch tip at various angles for cutting beveled-edged circular holes in flat sheet material.

2,547,432—Coated Welding Rod—William Andrews, Gateshead-on-Tyne, England, assignor to Metal and Thermit Corp., New York, N. Y.

This patent covers coating ingredients for use with an electrode comprising powdered minerals. The binder for the coating ingredients is an alkali metal aluminate having a molecular ratio of alkali metal oxide to aluminum oxide in excess of one. A metal oxide combinable with the excess alkali metal oxide is also included in the binder. The metal oxide is selected from the class consisting of the oxides of aluminum, titanium and zirconium, while the alkali metal is selected from the class consisting of sodium and potassium.

2,537,872—Welding Torch—Russell P. Kissick, Cincinnati, Ohio, assignor to Stacey Brothers Gas Construction Co., Cincinnati, Ohio.

This patent covers a welding torch wherein an electrode holder is pivotally carried on a handle for such electrode holder. The holder includes electrode securing means and an electrode is mounted in such means and extends axially the full length of the electrode holder to project above same. A removable insulated cap is mounted on the upper end of the electrode holder for covering the extended upper end of the electrode and provide an insulated hand hold for angular adjustment of the holder.

2,548,007—Welding Wheel—Wilbur G. Fitzsimmons, Ocala, Fla.

Fitzsimmons' patent is on a welding wheel which has a plurality of radially disposed chambers formed therein for receiving cakes of coolant material. The chambers have a closure provided therefor and they each have at least one gas vent provided therein.

2,548,230—Welding Mask—Cecil Patrick Molyneux, Hampton Bays, N. Y., assignor to Molyneux & Aspinwall, Inc., Flushing, N. Y., a corporation of New York.

This novel welding mask is provided for use with an electric arc-welding device. The mask has a set of eye pieces of variable light transmission and means are associated with the eye pieces for gradually varying the amount of light passing therethrough. Means directly responsive to variations in the current flowing in the welding device are provided to operate the means associated with the eye pieces for varying the amount of light passing therethrough during welding in accordance with variations in the current flowing in the welding device.

2,549,173—Seam Welding of Cylindrical Articles—Howard C. Cogan, Bay City, Mich., assignor to National Electric Welding Machines Co., Bay City, Mich., a corporation of Michigan.

This patent is on a specialized machine for making the cylindrical portion of a barrel by welding together the longitudinal parallel edges of a piece of sheet material bent into cylindrical form. The machine includes upper and lower circular electrodes which cooperate with vertically and horizontally spaced lap rollers to aid in positioning the sheet material and for effecting the welding action thereon.

JIM, HOW ARE WE GOING TO DO ALL THIS CUTTING AND WELDING... AND STILL MAKE DELIVERY ON TIME?
THAT NEW P&H ELECTRODE IS THE ANSWER, BILL. DH-4, THE FASTEST ROD WE'VE EVER BURNED!

NEW P&H DH-4 Electrode

For high-speed welding — cutting and gouging

...perfect X-Ray welds on heavy metal sections without machining or scarfing

This is the most unusual rod ever developed. It has so many applications that the American Welding Society does not have an AWS number for it.

Because of its wide range of usefulness the new DH-4 rod has shown outstanding economies in welding time and costs.

Here are a few of its many advantages: Fast deposition rate. Easy manipulation. Welds mild steel to mild steel without processing. Has extremely high penetration — 1/4-inch with 1/8-inch rod at 300 amps. Cuts time on horizontal fillet welds, flat butt welds, and vertical down welds. Ideal for gouging and cutting. Gives excellent results on Hadfield manganese and high-carbon steels.

If you want to give your production a lift and reduce your costs, you'll want to know more about the unusual DH-4. See your P&H representative or distributor. Write us for details.

3 SIZES AVAILABLE
1/8", 5/32" and 3/16"
Operates off DC welder on straight polarity or AC welder with minimum open-circuit voltage of 80 volts.

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Specialists in Stainless, Low Hydrogen and Non-Ferrous Electrodes

2,549,360—Welding and Cutting Torch—Peter Barbeck, New York, N. Y., assignor to Oxygen Arc Equipment Co., Inc., Brooklyn, N. Y., a corporation of New York.

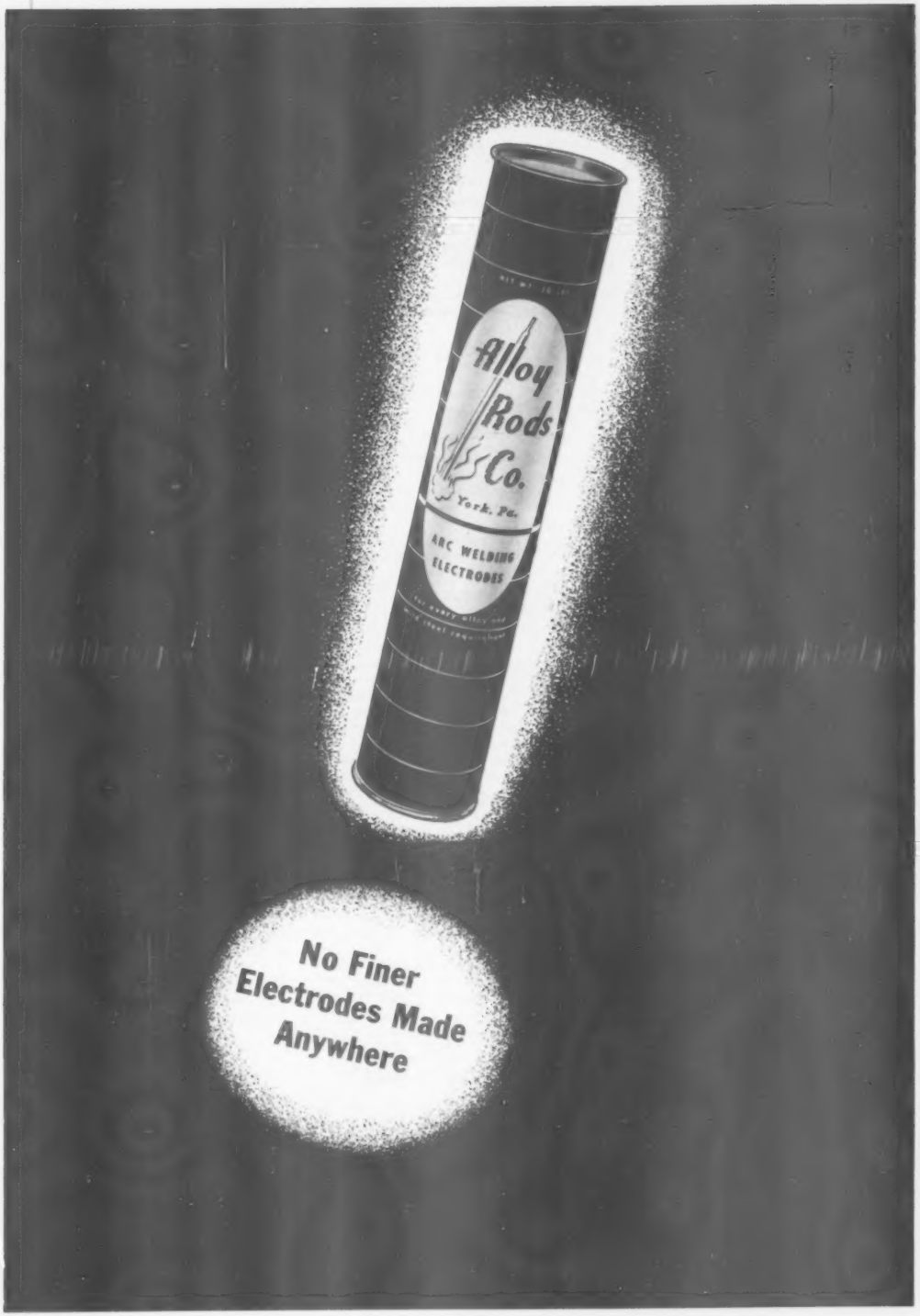
This special torch includes a body portion having a conduit member therein for passing a gas therethrough. A valve chamber is provided adjacent the entrant end of the conduit member while an electrode-ejecting chuck is at the other end of the conduit. The electrode-ejecting mechanism is provided in association with the chuck. The chuck has a gas passage through the body thereof for admitting gas to the bore of a hollow electrode secured therein. An antiflash-back formation is provided in the conduit member between the valve chamber and the chuck.

2,549,648—Welding Generator—Joseph M. Tyrner, New York, N. Y., assignor to Air Reduction Co., Inc., a corporation of New York.

This patent covers a direct-current welding generator including an armature and a main magnetic structure cooperating with the armature to form a main magnetic circuit for magnetic working flux and it includes a yoke and at least two pole pieces. An auxiliary magnetic structure forms an auxiliarly magnetic circuit for auxiliary leakage flux and it includes a yoke extension connected to the yoke and with the auxiliary magnetic circuit having a portion in common with the main magnetic circuit. Such portion carrying both the auxiliary leakage flux and the working flux is not saturated under normal operating conditions. A main field winding is about a portion of the main magnetic circuit other than the common portion thereof for producing substantially all of the working flux. An auxiliary winding is provided about the portion of the yoke extension other than the common portion thereof for producing flux in the common portion opposing the production of working flux by the main field winding.

2,549,736—Apparatus for Flame Spraying—Randolph A. Wiese, New York, N. Y., assignor to The Powder Weld Process Co., New York, N. Y., a partnership composed of Dorothy E. Wiese and Randolph A. Wiese.

Wiese's flame-spraying system comprises a source of fuel gas, a source of carrier gas, a source of fragmented material to be entrained in the carrier gas and then flame sprayed upon a targer, and a flame-spraying tool. Each of the sources is connected to the tool by a conduit having a reducing valve therein. A material-entraining chamber is provided in the conduit leading from the carrier-gas source while a valve on the flame-spraying tool regulates the flow of fuel gas through the tool. A metering tube communicates with the fragmented-material source and extends into the material-entraining chamber for delivery of fragmented material thereto.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York, Pa.
ARC WELDING ELECTRODES
No Finer Electrodes Made Anywhere

NEW LITERATURE

Heating, Ventilating, Air Conditioning Guide, 1951

A Technical Data Section of reference material on the design and specification of heating, ventilating and air-conditioning systems based on the *Transactions*, the investigations of the research laboratory and cooperating institutions and the practice of the members and friends of the society; a manufacturers' Catalog Data Section containing essential and reliable information concerning modern equipment; complete indexes to Technical and Catalog Data Sections.

Vol. 29, $7.50 per copy, 1456 pages. Published annually by American Society of Heating and Ventilating Engineers, 51 Madison Ave., New York 10, N. Y.

Tweco Literature

Tweco Products Co. has recently issued three pieces of literature:

1. *No. 8 TWECOLOG.* A 12-page catalog which pictures and describes the complete line of Tweco Products. Specifications, prices and a parts list are given on each product.

2. *Form No. CP-51 TWECO-BRIEF.* A four-page bulletin also illustrating and describing our complete line of products. Information is more condensed and parts lists are given only on TWECOTONG Holders and TWECO Ground Clamps.

3. *Form No. F-30 TWECO-MAILER.* A combination envelope stuffer and mailing piece. It contains practically the same information as the TWECO-BRIEF. No parts lists are shown.

Tweco Products Co., P. O. Box 666, Wichita 1, Kan.

Resistance Welding at Work

Sciaky Brothers, Inc., 4915 W. 67th St., Chicago 38, Ill., have just issued an attractive four-page circular describing how America's accelerating jet program has tremendously increased the use of resistance welding in all phases of aircraft construction. Copy available on request.

Safety Catalog Guide

Chuck full of over 500 different numbers on tested-proved nationally known products, on all engineering, welding, safety accessories and industrial protection clothing and devices.

Available on request on company letterhead, this Catalog is primarily issued for "men on the job" to aid their selection of most suitable products for their particular use. 70 pages. Parkars Safety Equipment Co., 785 Lyons Ave., Irvington 11, N. J.

Flame Hardening of Large Surfaces

A new reprint, "Flame Hardening of Large Surfaces," has been announced by Air Reduction Sales Co., a Division of Air Reduction Co., Inc.

This 6-page article, which originally appeared in THE WELDING JOURNAL, was written by J. J. Barry and discusses fundamental principles covering the adaption of flame hardening to present-day needs. Historical development of the process and equipment as well as description of modern methods and applications are discussed. Information regarding the new Airco high capacity flame-hardening torch also is included.

This article employs 17 photographs and sketches to illustrate principles discussed and to show some application of these principles.

Copies of this reprint (ADR 70) may be obtained without charge by writing to your nearest Airco Sales office or to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Severance Catalog

The new Severance *All Star* catalog is now ready for general distribution by Severance Tool Industries Inc., Saginaw, Mich. This new concise listing of the company's most popular items, including tools for the welding trade, will be helpful to the welding and allied industries.

New "Slope Control"

A short article on this subject by Charles Bruno, Chief Welding Engineer, describes how tip life may be lengthened and weld quality improved on spot-welding aluminum. The Bulletin No. is 15. Copy available on request. Reynolds Metals Co., Technical Editorial Service, 2500 S. Third St., Louisville 1, Ky. G. W. Birdsall, Editor.

Taylor Forge Catalog

The new Taylor Forge Catalog 501 describes and illustrates Taylor forge nozzles, welding necks and large diameter flanges. Also included in this catalog are data covering standards of the Tubular Equipment Manufacturers Association (TEMA Standards). The Taylor Forge publication, *Modern Flange Design*, is also incorporated as a part of this catalog.

This catalog is available to anyone having a specific interest in pressure vessel work. Taylor Forge & Pipe Works, Inc. P. O. Box 485, Chicago 90, Ill.

Welding of Gray Iron

A comprehensive pamphlet on "Welding, Joining and Cutting of Gray Iron" has been prepared by the Gray Iron Founders' Society, Inc., 210 National City-East 6th Bldg., Cleveland 14, Ohio, under the direction of C. O. Burgess, Technical Director.

Gray-iron castings can be economically welded with full success using new processes and improved techniques described in this manual. All the advantages of welded fabrication, previously considered as limited to steel parts, can now be extended to gray iron components. The engineering considerations which make a certain welding process or combination of welding processes—gas, arc, inert-arc, braze, brazing, thermit, flash, etc.—most suitable in a given case are fully outlined. The techniques by which each process can be made to yield sound, dependable gray-iron welds is set forth.

Complete Handbook on Properties and Working of Stainless Croloy Tubes and Pipe Offered by B&W

A complete handbook, *The Properties and Methods of Working Seamless and Welded Tubes and Pipe of the B&W Stainless Croloys*, is offered by the Babcock & Wilcox Tube Co. Intended for engineers, designers and fabricators, it is designed to serve as a guide in choosing the proper material and as a help in planning the conversion of stainless steel tubing into finished products for industry. The 104-page leather-bound booklet is eight by five inches, a handy size for desk or pocket.

Copies of the booklet, known as *Technical Bulletin 1B*, are available free on request to the company's offices at Beaver Falls, Pa.

Mogul Impregnating Process

Just published is a new 8-page bulletin, *Mogul Cast-Seal Impregnating Process*, by the Metallizing Company of America, 3520 W. Carroll Ave., Chicago 24, Ill. The bulletin fully explains the equipment used in this process, claimed to be a positive, low-cost method of eliminating casting porosity.

Salvaging Operations

The salvaging of cement mill gears, Pitman bearings, swaging machine spindle caps, street railways in Belgium to fabricating a fractionating tower is covered in the first quarter issue of the "Ampco Welding News." The advantages of Ampco Weld "Cold Bent" resistance-welding electrodes and the Ampco Spray Booth Kit are also included in this issue which is yours for the asking. Write Ampco Metal, Inc., 1745 S. 38 St., Milwaukee 46, Wis.

The Practical Engineer, Pocket Book 1951

In preparing this new edition the type has been completely reset, many of the illustrations have been redrawn and the separate sections have been rearranged in a more logical sequence. Despite these changes, however, the traditional character of the book has been retained.

The internal combustion engine section has been extended to include information on the properties of compression ignition engine fuels, and a brief section has been added on the supercharging of engines. In view of the growing importance of the gas turbine, a new section has been written to serve as an introduction to this specialized aspect of power engineering. Basic data on the proposed unified standard screw threads have been included; these are provisional, and the section will be extended when the specifications are finalized. The list of technical journals has been revised and expanded to include a selected list of American journals. A German dictionary has also been added to those in French and Spanish.

Edited by N. P. W. Moore. Price $3.00. Published by Pitman Publishing Corp., 2 W. 45th St., New York, N. Y.

"Do's" and "Don't's"

The six "do's" and the two don't's" of sound procedure in using All-State Silver-Brazing Alloys are fully covered in a new issue of a miniature folder which has just been released on the All-State dispenser for these valuable materials.

These "do's" and "don't's" while simple and brief are especially helpful to those turning to the silver solders to replace harder-to-get, more critical materials.

Copies of the folder (4 pp., 3 x 3¼ in.) are available from All-State distributors everywhere and from All-State Welding Alloys Co. Inc., 273 Ferris Ave., White Plains, N. Y.

Arc Welders

Selenium Rectifier Type D.C. Arc Welder Bulletin, Miller Electric Mfg. Co., Appleton, Wis. describes three new models, features of design and performance, with complete specifications of each model.

McKay Manual

The Welding of Stainless Steels is a new handbook published by the Electrode Division of the McKay Co., Pittsburgh, Pa. Its 48 pages describe in complete detail all phases of Stainless Steel Arc Welding. Its contents will be found useful by welders and welding engineers, designers, salesmen, service personnel and purchasing agents.

The Handbook discusses and illustrates through charts such valuable technical information as the metallurgical background, specific uses of alloying elements and facts in general pertaining to the welding of Stainless Steels. Also shown in detail is the A.I.S.I. Analyses, analysis

range, color guide and tensile data of the various groups of Stainless Steels.

Included in the 48 pages is pertinent data concerning uses and specifications of each type of McKay Stainless Steel Electrode and information about the three types of coatings used for each electrode.

This informative manual, "The Welding of Stainless Steels," is available upon request from the McKay Co., 303 McKay Bldg., Pittsburgh 22, Pa.

Buy "PROVEN FLUXES"

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"ANTI-BORAX" FLUXES

Insist on them — Unequalled Quality

No. 1 Cast Iron Welding Flux
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No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

Mfg. By
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Fort Wayne, Ind.

WELDING CONNECTORS

Saxe System Welded Connection Units for welded assembly

Saxe Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

"Write for 58 pg. Manual containing full engineering design information for welded structures"

J. H. Williams & Company
Buffalo 7, New York
Air Reduction Canada, Ltd.
Montreal 2, Canada
Canadian Representative

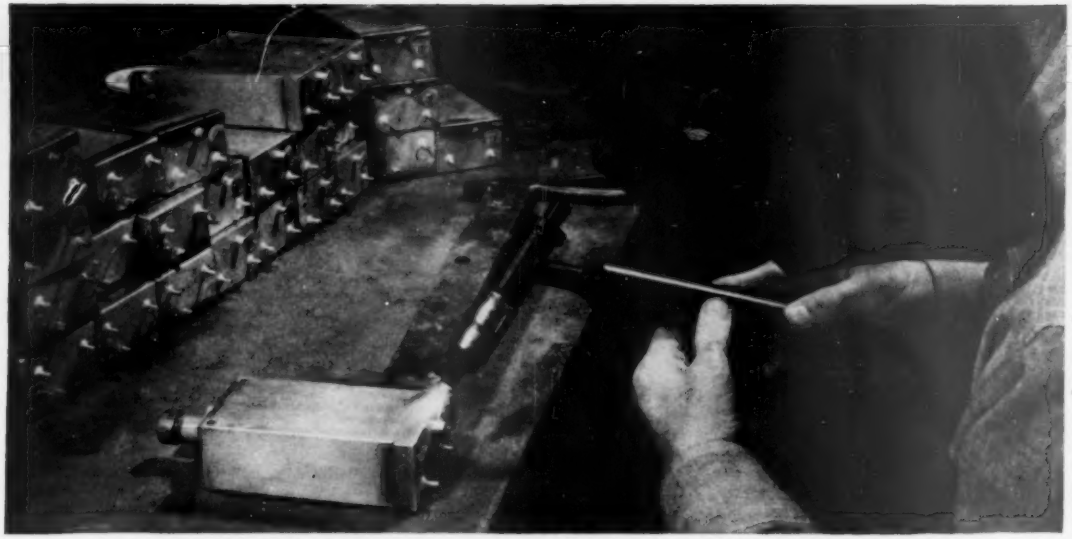
D-C WELDER SAVINGS PROVED AGAIN IN THE FIELD

Take the case of the 2,000,000-gallon water tank erected by the Pittsburgh-Des Moines Steel Company at Niagara Falls, New York. A battery of D-C Rectifier Welders fed by one large diesel generator replaced a number of diesel-driven welding generators formerly used.

Maintenance was reduced 85%—weight was slashed by 15,000 pounds—initial cost was cut 50%—fuel savings totaled $8.70 a day!

For your welding application —large or small—call your nearest Westinghouse Representative or write Westinghouse Electric Corporation, Welding Division, Buffalo, New York. J-21605

YOU CAN BE SURE... IF IT'S Westinghouse D-C Welders



Here, G-E Inert-Arc welding is used to weld the seam on a "buzz box," source of the spark which ignites the fuel in jet engines.

WHY G-E INERT-ARC WELDERS CAN SPEED UP YOUR DEFENSE PRODUCTION

You can speed up the fabrication of ship and plane parts made of aluminum, magnesium, or copper alloys by using General Electric a-c Inert-Arc welders because they are specially designed for welding these materials. They give your operators many features not found in "jury-rig" modifications of ordinary a-c metal-arc welders.

Exclusive "Balanced Wave" Design

Balanced-wave design, for example, an exclusive feature of G-E Inert-Arc welders, enables your operators to increase travel speeds, make stronger welds, and reduce power and gas consumption.

"Idlematic" Control for Safe, Simple Operation

The high-frequency pilot, the flow of gas, welding current, and cooling water are controlled by the use of G-E "Idlematic" control. This permits the operator to save time and reduce spoilage by making it easy to start the arc at the proper spot on the work because he can position the electrode with his hood up.

Crater-filler or Remote Control

On applications requiring weld craters to be level at the end of each weld bead, use of the optional G-E crater-filler will enable you to do the job quickly. Where desired, a hand or foot switch can be furnished to allow continuous stepless current control while welding.

Write for Free Bulletin

For detailed information on how you can speed up fabrication of aluminum and other alloys, write for bulletins GEC-596 and GEC-653. *General Electric Company, Schenectady, N. Y.*

G-E Inert-Arc welders are easy to use. Simply touch the electrode to the work and you're off to a quick clean start—and without using flux. The welders are available in 200-, 400-, and 800-ampere ratings.

G-E "BALANCED WAVE" GIVES STRONGER WELDS, FASTER TRAVEL SPEEDS—with reduced power and gas costs

Key to the advantages of the G-E "balanced-wave" Inert-Arc welder is the use of series capacitors in the output circuit. These capacitors block the d-c current which would otherwise be produced by the arc, and make it possible to get an even, uniform flow of a-c current.

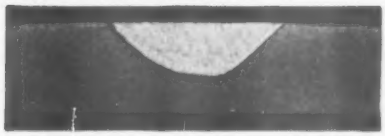
This design, with the high-frequency pilot used only for starting, eliminates objectionable radio interference caused by welders using continuous high frequency.

You Get Stronger Welds, Faster Travel Speeds

Under identical conditions G-E "balanced-wave" welders give you a greater depth of penetration, better bead contours, and greater fusion area than welders with unbalanced-wave circuits.

This means, therefore, that an operator can do the job faster by using the G-E equipment.

"Balanced Wave" of G-E Inert-Arc Welders Produces Deep Penetration, Wide Fusion Area

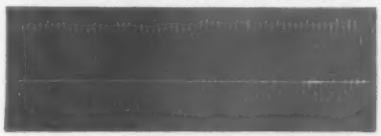


Unbalanced Wave of Ordinary a-c Metal-arc Welders Produces Shallow Penetration, Narrow Fusion Area

Above macrosections are from two pieces of ¼-inch aluminum, on which beads were run without the addition of filler metal, and under identical welding conditions.

G-E Inert-Arc Welders Give Even Flow of Current

Conventional Shielded-arc Welders Give Uneven Flow



Steady current from G-E "balanced-wave" welder gives better welding at lower cost than unbalanced-wave currents from shielded-arc equipment.

G-E Inert-Arc Welders Can Reduce Your Power and Gas Costs

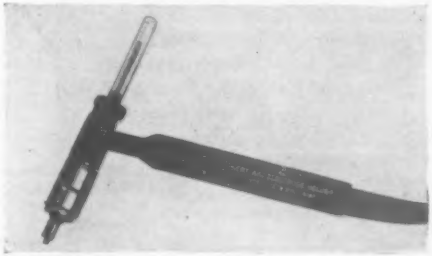
Because your operators can weld faster with G-E Inert-Arc welders, less gas and power are consumed. Saving in power costs and gas consumption have been estimated as high as 25% using G-E Inert-Arc welders, because of Idlematic control, series capacitors and momentary high-frequency pilot.

Holders and Tungsten Electrodes Are Designed for High-speed Work

An operator can adjust by hand a tungsten electrode in the illustrated holder. No wrenches are required.

And he can do a wide variety of jobs with the same holder. Using it with a 200-ampere G-E Inert-Arc welder, for example, an operator can weld both light- and medium-gage materials, with electrodes up to eight inches in length in diameters of .040, $\frac{1}{16}$, $\frac{3}{32}$, $\frac{1}{8}$, and $\frac{5}{32}$ inches.

To give you the right electrode for any job, G.E.'s 99.9% pure tungsten is available in a wide variety of diameters and lengths in both standard and thoriated types.



Holders for G-E Inert-Arc welders are available for any current requirement from 15 amperes to over 800 amperes, a-c or d-c.

ASK ABOUT G.E.'s THORIATED TUNGSTEN

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GENERAL ELECTRIC

7JJ-15

SECTION ACTIVITIES

prepared by C. M. O'Leary

Anthony Wayne

The April meeting of the Anthony Wayne Section was in the form of a plant visit and was held on Friday, April 20th. Seventy members and their guests met at the Wishbone Cafe, Huntington, Ind., at 6:00 P.M., where dinner was served.

Following the banquet, the group proceeded to the Orton Crane & Shovel Co. Here they were met by guides and, forming into groups, were conducted on a tour through the plant. The Section feels that the management of the Orton Crane Works should be highly commended for the cooperation and courtesy shown the A.W.S. Section. Their plant at this time is working one shift per day. Because of the A.W.S. visit, the management called their employees back to work and paid them overtime so that the visitors would have an opportunity to see the plant in operation.

The Section greatly appreciated this gesture and were extremely happy that they have a plant in their area which will cooperate with the A.W.S. to this extent. The tour was very educational and highly enjoyable. In preparing for the visitors they had a number of various type cranes and shovels in all stages of construction so that they might follow step by step the fabrication of this equipment. They were pleased to see the number of weldments used in the welded construction of this machinery. Very, very few castings were utilized. Flame-cutting operations were considerable as was their entire welding operation.

Many of the group, who had never seen welding production on this scale, were amazed at the scope of welding at Orton's. Naturally, it enhanced their knowledge as well as their opinions of welding.

Arizona

On Wednesday, April 18th, a dinner meeting was held in the Pompeian Room of the Hotel Westward Ho by the Arizona Section. Approximately forty-five members and guests attended the dinner and over fifty the technical meeting which followed.

The speaker of the evening was Walter E. Riley, member of the consulting engineering firm of Riley and Foltz, Phoenix, Ariz. Mr. Riley is the Technical Representative and also Secretary of the Arizona Section.

The subject of his talk was "Fundamentals of Welding Design." He discussed the various welding processes, the characteristics of the metallic arc, types of welds, design considerations, stress concentrations, properties of joints at low temperatures and under impact loading, fatigue, welding metallurgy and inspection of welds. Mr. Riley's talk was well received and made particularly interesting by the use of very descriptive slides.

Boston

The Boston Section's Annual Meeting for the election of officers was combined with a plant visit at the Avery & Saul Co., Cambridge, Mass., on Apr. 9th, with an attendance of 173 members and guests.

A cocktail and social hour was followed by a dinner at 6:45. This was followed by a business meeting at which the following officers were elected: *Chairman*, H. Hugo Stahl, The Lincoln Electric Co., Boston; *Vice-Chairman*, P. Edward McKenna, United States Steel Supply Co., Boston; *Secretary-Treasurer*, Louis I. Dexter, Rumford Steel Products, Inc., Providence, R. I.; *Trustee*, James Donovan, Artisan Metal Products, Inc., Waltham; *Directors* (for two years), Harry J. Ferguson, Allen G. Hogaboom and Herbert Turck.

The members and guests then visited the plant in operation. The various steps in the manufacture of large machine parts were very efficiently demonstrated.

Chattanooga

The April meeting of the Chattanooga Section was held April 6th at the Maypole Restaurant in Chattanooga.

The main speaker for the technical session was E. C. Hutton, Industrial Engineer with R. G. LeTourneau, Inc., Georgia Div. Mr. Hutton began his talk with a description of the functions and design of several LeTourneau earth-moving and construction machines. The rest of his talk covered the use of welding in the fabrication of these products, how weld design is established, quality control maintained and how production rate and costs are estimated. He also discussed some aspects of the training and wage classifications of welders.

Dr. Hutton's talk was both interesting and informative.

Chicago

The March meeting of the Chicago Section was held on the 16th at the Peoples Gas Light & Coke Co. auditorium. Dinner was served at Burke's Grill. An attendance of 115 was reported at the meeting and 53 at the dinner.

John Hruska, consulting engineer, gave a clear-cut discussion on "The Present Status of Automatic Electric Welding." Mr. Hruska is extremely well qualified to discuss this subject as he has had extensive experience in this field.

Before the meeting a movie "Wings to Bermuda" was enjoyed by all.

The April meeting was held on the 20th with an attendance of 130 at the meeting held in the Peoples Gas Light & Coke Co. auditorium and an attendance of 49 at dinner held in Burke's Grill.

Anton L. Schaeffler of Allis-Chalmers, Milwaukee, was the speaker at the technical session. Mr. Schaeffler's subject, "Simplified Metallurgy for Welders and Welding Supervisors," was highly interesting.

A movie, entitled "Mexico on Parade," was shown before the meeting.

Cleveland

The April meeting was held on the 11th at the Allerton Hotel, Cleveland, Ohio, with an attendance of 53 at dinner and 67 at the meeting. Dinner speaker was Joseph A. DiTirro, whose talk on "The Diamond Industry" was well received.

Speaker at the technical session was Raymond M. Dennis, By-Products Steel Co., Division of Lukens Steel Co. Mr. Dennis presented an illustrated talk on "Cutting and Shearing of Mild, Stainless and Clad Steels," which was also well received.

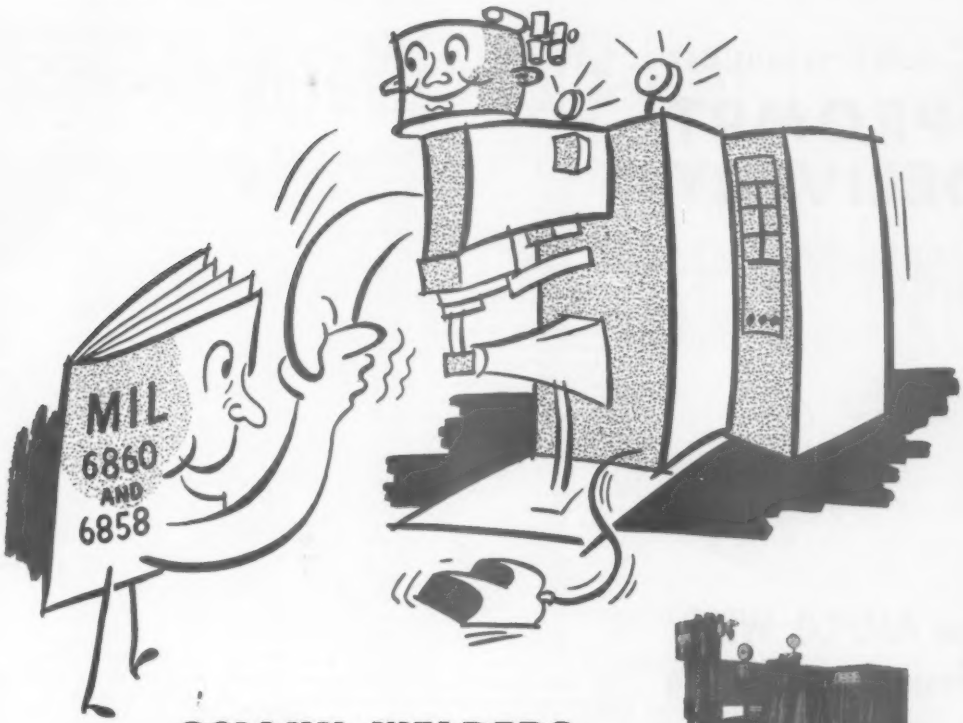
Colorado

The April dinner meeting of the Colorado Section was held on the 13th in the Festival Room of the Oxford Hotel, Denver. Speakers at the meeting were W. L. Davis, Project Engineer, and A. W. Hall, Metallurgist, of the Hathaway Instrument Co. An extemporaneous talk was given on the applications of welding to their business.

After the meeting a 1950 World Series movie was shown through the courtesy of the National and American Baseball League.

Columbus

A dinner was held in connection with the 12th Annual Ohio State University



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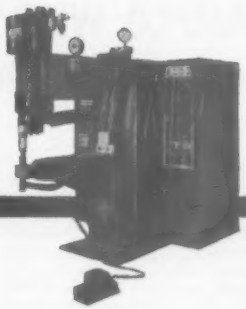

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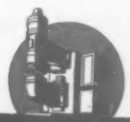

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Welding Conference on April 13th at the Fort Hayes Hotel. Toastmaster was Michael S. Shane of Cleveland Electric Illuminating Co. Speaker at the dinner was J. G. Magrath, Secretary of the American Welding Society.

Speaker at the technical session was Harry L. Pierce, President of the American Welding Society and Assistant to the President of the New York Shipbuilding Corp., Camden, N. J. Mr. Pierce's subject was "Distortion and Dimension Control in Shipbuilding."

Cumberland Valley Division

On April 23rd, the Cumberland Valley Division members and guests enjoyed a well-balanced program of talk and pictures. C. N. Hilbinger of the Lincoln Electric Co., accompanied by Joseph F. Gulley, journeyed to Hagerstown with good intent and firm purpose, and accomplished same. Mr. Hilbinger's subject was "Design, Machine and Structural." Beginning with the early history of welding he told how the welding industry increased the use of steel as engineers learned to design strictly for welding. Many colleges now present programs which deal with welding not as a sideline but a full grown industry. Mr. Hilbinger used three motion pictures to good advantage.

Many guests from Baltimore were present to see their "little brother." It is worth mention that Hagerstown is somewhat separated from other A.W.S. activities. G. E. Claussen, A. L. Lees, Fritz Albrecht, Lytle H. Mathews and George Matzembecker all traveled 75 miles to continue the Maryland Section's most bountiful assistance to the Cumberland Valley Division.

The Washington Section was also represented in the persons of Mr. and Mrs. McPherson.

Dallas

The April 11th meeting was held in the Lone Star Gas Co. auditorium. Speaker at the technical session was Austin F. Leach of the General Electric Co., who spoke on "Welding Electrodes."

Dayton

A joint meeting with the American Institute of Electrical Engineering Society in Dayton was held on April 18th at the Dayton Engineers Club.

The meeting was started with a colored movie on tuna fishing off Nova Scotia. The movie was excellent and surely whetted a lot of fishermen's appetites.

The technical session of the meeting was started with a color movie showing the operation of a high-speed barrel seam welder developed by the National Electric Welding Machines Co.

Howard C. Cogan, Vice-President of National Electric Welding Machines Co., then talked on the various factors involved in designing welding machines for high-production work and told of some of the actual experiences they had had with high-production machines. One particularly interesting story brought out the fact that it was not only necessary to design the machine from an engineering point of view but also from a production point of view. In this case a machine had been designed to make automobile fenders and was arranged to make one left-hand fender and one right-hand fender simultaneously. Actual production experience requires, however, that about twice as many left-hand fenders be made as right-hands because of replacements due to accidents. This made this particular machine somewhat unsuitable for actual production work.

Dean Knight, Chief Welding Engineer of National, followed Mr. Cogan with a discussion of some of the engineering principles involved in the latest type of electric welding machines, particularly in respect to the low-frequency, three-phase power supply systems.

The June picnic date has been changed to June 19th at the Frigidaire Gun Club.

The meeting was closed with the serving of refreshments.

Detroit

The regular monthly dinner meeting of the Detroit Section was held on the 13th at the Engineering Society of Detroit, with an attendance of 60 at dinner and 107 at the meeting. This meeting was probably one of the most outstanding of the year from the standpoint of general interest. Red Jones (a former American League Umpire who now represents the Pfeiffer Brewing Co.) presented a most unusual after-dinner talk during which he related many amusing experiences from his umpiring career.

After dinner, at the regular technical session, a movie was shown on "Designing Machinery for Arc Welding" which was supplied by the Lincoln Electric Co. Following the film, Mr. Blodgett of the Lincoln Electric discussed welding design and the use of innumerable short-cut equations and methods to be employed by the welding designer. The contents of Mr. Blodgett's talk should provide the ordinary layman in the welding field with a simple means of calculating stresses and loads in arriving at weldments of adequate strength.

Succeeding Mr. Blodgett, George Harding showed a color film entitled "Hunting Mountain Lions in Utah" which was extremely interesting, as were Mr. Harding's running comments on the pictures. At the completion of this movie, Mr. Harding said he had also brought with him a sound color film entitled "Tarpon Fishing in Florida," and asked if those present were interested in seeing it. The response was a unanimous "yes" and this film was equally as interesting as the hunting film.

Hartford

The New England Joint Meeting with Hartford Section as the host took place on April 12th. A visit through the two plants of the Farrel-Birmingham Co. in Ansonia and Derby, Conn., was enjoyed by 100 A.W.S. members from all around New England.

At the dinner held at the Race Brook

Solar Aircraft Welds Close to the Edge

Material does not split out, spattering is reduced on this jet engine part because G-E slope control permits a gradual increase in welding current that also reduces tip pick-up and spatter. More welds can be made before electrodes must be cleaned. Welds are sound and uniform. Bulletin GEC-534.

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Be sure of consistent, high-quality welds with these G-E Accessories

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GENERAL ELECTRIC

645-54

Group at head table at dinner of the New England Joint Meeting held on April 12, 1951. Left to right: John Light, past chairman, Hartford Section; John Mortimer, secretary of Hartford Section; Harold Grosberg, chairman of Bridgeport Section and Farrel-Birmingham welding department foreman; F. Wallace, vice-chairman, Hartford Section; Lewis Sykes, chairman of Hartford Section; Carl Hitchcock, vice-president and general sales manager, Farrel-Birmingham, and Edward S. Coe, F-B plant manager

Country Club each person received a matching set of Farrel-Sykes continuous-tooth double helical gears and two bulletins on the Farrel-Birmingham Co. and their products.

The meeting was addressed by Carl Hitchcock, Vice-President and Sales Manager, Farrel-Birmingham Co., who spoke on the Farrel-Birmingham products and installations.

Houston

The April dinner meeting of the Houston Section was held on the 12th at the Ben Milam Hotel with an attendance of 82 at dinner and 85 at the technical session.

Speaker at the technical meeting was A. F. Leach of the General Electric Co., whose subject was "Welding Electrodes and Their Characteristics."

A motion picture film, "A New Frontier," was also shown.

Kansas City

The April 19th dinner meeting of the Kansas City Section was held at Fred Harvey's, Union Station.

Chairman Rudd introduced Wendell E. Matchett of the General Electric Co. who gave a short talk on the basic characteristics of the various electrode classifications.

Mr. Matchett, in turn, introduced Austin Hiller of the General Electric Co. who talked on "Low-Hydrogen Electrodes." Mr. Hiller's talk was illustrated with slides, followed by a short discussion period.

Michiana

On April 19th the Michiana Section met at Clark's Restaurant to hear Gordon Parks, Welding Engineer of Solar Aircraft Co., Des Moines, Iowa, describe welding methods used at his plant on various components used in aircraft construction.

Mr. Parks opened his discussion with a short history and description of jet engines. Solar's specialty being fabrication of heat-resistant materials, it was only natural that they be called upon to make many of the metal parts used in a jet's "innards," where high temperatures are encountered. The bulk of the talk was concerned with resistance methods, since seam and spot welding account for such a major portion of their welding procedures. Most of this type of welding is done on straight a.-c. welders. The talk was illustrated with slides.

New Jersey

The New Jersey Section held its regular monthly meeting at the Essex House Hotel, April 17th, with 76 in attendance.

The technical speaker was R. M. Wilson, Welding Engineer of the International Nickel Co., Inc., and Past Chairman of the New Jersey Section. Mr. Wilson presented an interesting and informative talk on both physical and mechanical properties of cast and wrought nickel and nickel alloys which included Duranickel, the Monels and Inconels.

The winner of the free dinner for the May 22nd meeting was Carroll Hansen of Foster Wheeler Corp.

Refreshments were served after the meeting.

New York

"Shop Problems in Welding" was the title of the paper presented before the New York Section by Harold E. Baldwin, Manager, Process Control Div., R. G. LeTourneau, Inc., Peoria, Ill., at the April 10th meeting.

Basing his talk on the experiences of the LeTourneau organization, one of the companies which has pioneered in the field of welded fabrication, Mr. Baldwin outlined the history of his company and sketched verbally their rapid growth to their present eminent position in the industry. Mr. Baldwin described the organization of his company and stressed the importance they place on welding as the most economical and feasible fabrication method for constructing the earth-moving machinery the LeTourneau Co. makes. He pointed out that by judicious application of welding methods they had almost entirely gotten away from the use of castings and were presently using only the barest minimum number of forgings in the construction of their products. By so doing, R. G. LeTourneau, Inc., has been able to reduce their costs phenomenally and to build a product which stands the rugged service conditions encountered in this field.

Mr. Baldwin discussed at some length their success in developing electrodes of their own manufacture for welding the many different types of steels, including high-carbon and alloy steels, which are used in the construction of earth-moving equipment.

An important topic covered by Mr. Baldwin was the use by his organization of semiautomatic submerged arc welding employing the "squirt" gun.

Without question, the audience was impressed with Mr. Baldwin's paper and gained many valuable suggestions from the experiences of the LeTourneau Co. in the welding fabrication field.

The meeting was in charge of John Mikulak, Assistant to the Vice-President in charge of manufacturing, Worthington Pump and Machinery Corp., Harrison, N. J. Mr. Mikulak also served as Technical Chairman of the meeting.

Before commencement of the technical session, a motion picture entitled, "Karat Gold," was shown through the courtesy of Handy & Harman, New York. This motion picture which was in color described the quality control of carat gold and showed many of the manufacturing processes and applications of fine gold in the jewelry industry.

This meeting, which was the last technical meeting of the 1950–51 season, was held at Schwartz's Restaurant, 54 Broad St., New York, where members and their guests enjoyed dinner before the presentation of the after-dinner program and Mr. Baldwin's outstanding paper.

Niagara Frontier

The April 26th dinner meeting of the Niagara Frontier Section was held at the Sheraton Hotel, Buffalo, N. Y., with an attendance of 71 at dinner and 96 at the technical meeting.

Speaker at the technical session was Arthur N. Kugler, Mechanical Engineer, Air Reduction Sales Co., whose subject was "Brazing and Braze Welding," and was very well received.

A plant visit was also made to the Morrison Steel Products Co., Buffalo, by 78 of those present.

The following officers and directors were announced as elected for the year 1951–52: G. Fitch Cady, *Chairman;* Charles W. Lytton, *Vice-Chairman;* R. T. Breymeier, F. L. Rodgers, Jr., and R. P. Gehring, *Directors* for a 3-year term.

Northwestern Pennsylvania

The March 20th dinner meeting of the Northwestern Pennsylvania Section was held at the General Electric Community Center, Erie, Pa.

Speaker at the technical session was Alden W. Swift of Handy & Harman, whose subject was "Silver Brazing as Applied to Mass Production." A film, "Production Silver Brazing," was also shown. Excellent interest was displayed in both the presentation and the film.

The April 18th dinner meeting was held in Soudan's Restaurant, Erie, Pa. Stephen Smith presented an illustrated talk on "Flame Hardening at National Forge and Ordnance Co."

A social hour followed the showing of two films.

Pascagoula

The regular monthly dinner meeting of the Pascagoula Section was held on April 25th at the Pascagoula Country Club.

Coffee speaker was T. J. Dawson of the Ingalls Shipbuilding Corp., who also introduced the speaker J. F. Bryan, Jr., of the American Bureau of Shipping, whose subject was "Ship Welding."

Philadelphia

"Titanium Metals and Alloys Containing Titanium" was presented in a most able manner at the March 19th meeting of the Philadelphia Section by Lee Busch, Metallurgical Engineer, P. R. Mallory & Co. The reception of this subject by 128 of the members and guests from the American Society of Metals well justified the scheduling of this new and interesting subject which is steadily assuming a role of importance.

Mr. Busch presented the development and background of titanium metals very thoroughly before elaborating on its current practical uses. Admittedly the surface has only been scratched in working with these metals but it was readily apparent that titanium metals, a weldable material, is and will continue to be of interest to members of the AMERICAN WELDING SOCIETY. E. M. Mahla, E. I. du Pont de Nemours & Co., acted as discussion leader for the questions and discussion which emphasized the interest and concern in these new metals.

Before the meeting the new members of the Philadelphia Section were introduced to the members at the meeting and officially welcomed to the SOCIETY.

Following the dinner which preceded the meeting, George Whittam, Manager, Customers Service Dept., Gimbel Bros., spoke on "Consumer Complaints." He presented the tremendous problem that faces the department stores in maintaining the best possible customer relationship. It was readily apparent that department stores have troubles and problems the same as we do.

The final panel discussion for this season was held on Apr. 6, 1951. This meeting was held as an open meeting at which any and all problems could be raised and receive consideration by a member of the panel which was composed of men well qualified in the various phases of welding. The panel was made up of the following men: John Lang, Welding Engineer, Lukenweld Division of Lukens Steel Co.; Hallock C. Campbell, Associate Director of Research & Engineering, Arcos Corp.; Walter Mehl, Chief Welding Engineer, Heintz Mfg. Co.; K. Wm. Ostrom, K. W. Ostrom Co.; and R. A. Quenzel, District Manager, Southern Oxygen Co.

The discussion of the questions that were raised was most beneficial and informative. This and all the panel discussion meetings throughout the year have been very helpful in answering the specific application problems that have been asked by our members.

The final technical meeting of the Phila-

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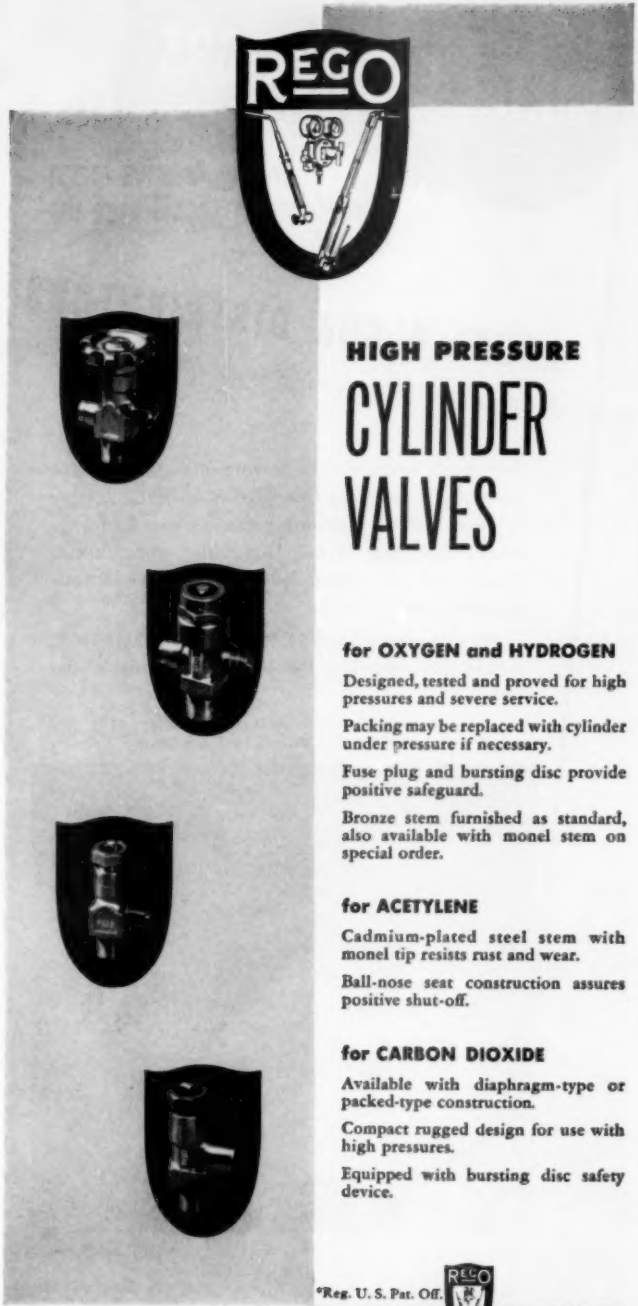
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delphia Section was of the same high quality that has characterized the meetings during this past year.

Otis R. Carpenter, Director of the Works Control Laboratory, Babcock & Wilcox Co., Barberton, Ohio, spoke on the "Factors in the Processing of Steel That Effect Weldability." He presented in a most able fashion what we can expect from various steels and the precautions that we should take. He illustrated the experience of the Babcock & Wilcox Co. with various materials by showing several interesting slides.

As usual the discussion following this talk, under the leadership of A. John Erlacher, United Engineers & Constructors, Inc., focused the attention on particular phases that most concerned the members present. Without question everyone concerned with welding of necessity becomes concerned with the steels that he must use.

Before the start of the technical session, several annual and important items of business were transacted. The Annual Treasurer's Report for the past year was read. The sound financial condition of the Section is something of which the Section can be proud. The results of the election of Officers for the ensuing year were announced with the following men elected.

Section Chairman, K. W. Ostrom; *Vice-Chairman*, R. A. Guenzel; *Secretary*, A. J. Erlacher; and *Treasurer*, E. R. McClung.

Members of the Executive Board (for a term of 3 years): J. S. Douglas, A. M. Garcia and C. W. Middlestead.

Members of the Executive Board (to fill unexpired term for two years): M. W. Brewster and E. B. Walker.

The results of the membership drive and contest were given and the goals that the Section hopes to attain before its conclusion were again emphasized. New members, not previously recognized, were introduced to the members present at the meeting.

Portland

The sixth meeting of the current 1950–1951 season was held Tuesday night, March 27th, at the Mallory Hotel, Portland, Ore. An informal dinner was enjoyed from 6:30 to 7:30 P.M. Due to the length of program material, the usual business formalities were eliminated.

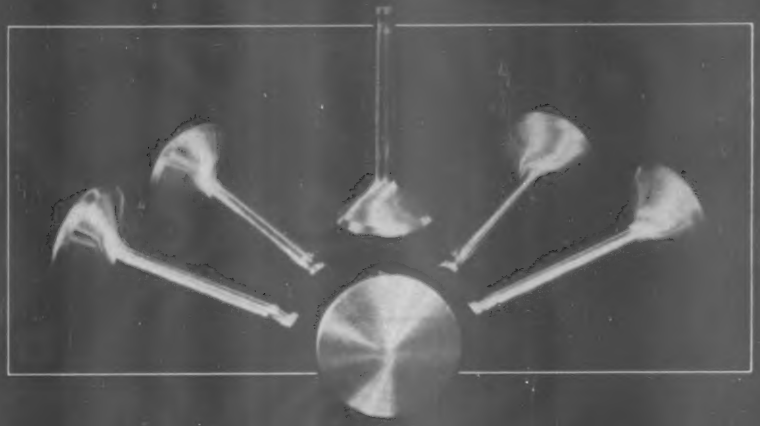
First on the program was Elmer E. Gunnette, District Engineer, American Institute of Steel Construction. He presented an interesting talk on the part welding plays in the erection of steel structures. Problems pertaining to adequate inspection and quality control were discussed.

Following this discussion, E. H. Weil, Program Chairman, introduced J. W. Magrath, National American Welding Society Secretary, who spoke on the problems, accomplishments and future plans of the American Welding Society.

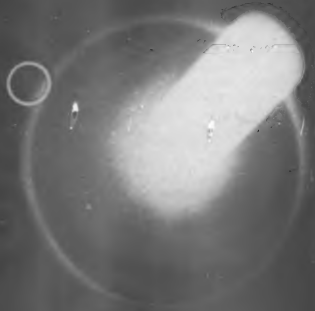
Approximately thirty-five persons attended the meeting which adjourned at 9:30 P.M.

Puget Sound

The April meeting of the Puget Sound



When minimum specs hit tops . . .



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Section was held at the New Washington Hotel, Seattle, Wash., with an attendance of 60 members and guests. A very interesting and informative paper was given by Myron Stepath, Welding Engineer for the Puget Sound Naval Shipyard, on the subject of Aircomatic Welding. A film was shown, supplementing his paper, entitled "The Tool for the Job." This paper covered both technical and practical aspects of the subject. A lively discussion followed the paper and film in which many of the fabricators in the Puget Sound area participated.

This Section was honored on March 28th with a visit from Joe Magrath, Secretary of the A.W.S. A dinner was held in Mr. Magrath's honor in the New Washington Hotel where he went into some detail concerning the future plans of the SOCIETY pertaining to the furthering of membership in welding engineering and also covering the phase that the SOCIETY should play in operator qualification tests. After some discussion, it was the unanimous opinion of those present that this was a very good, long-range program and that if it could be worked out whereby many of the members were actually welding engineers, and operators could be qualified under a standard set-up by the A.W.S., which would be acceptable to industry throughout the country, it would be a great benefit to the SOCIETY as a whole.

Rochester

A dinner meeting of the Rochester Section was held on March 26th at the Century Sweet Shop.

Charles Lytton of the Lincoln Electric Co. spoke on the "Cost Factors in Welding." He emphasized the importance of joint design, electrode selection, machine settings and positioning work. A good discussion followed.

Part II of the movie "Steel Making" was shown. Everyone has expressed their appreciation of this series of movies.

The membership drive is progressing very well and last reports indicate that this Section will have several Sustaining Members.

St. Louis

The St. Louis Section held a very interesting meeting on Apr. 13, 1951, with attendance at a predinner meeting of 40 members and 70 members attending the technical session. James E. Brown, Welding Engineer of the Allis-Chalmers Mfg. Co. presented a very enlightening talk on "Production Techniques in Manufacturing Small and Medium Sized Weldments." He displayed various slides depicting the application of welding to large weldments as utilized in the construction of Diesel tractors in the Springfield, Ill., works of his company. A lively question-and-answer period followed the meeting which provided many interesting discussions relative to cost reductions and welding procedures.

Washington

The regular technical meeting for March was held on March 27th and was preceded by dinner at O'Donnell's Restaurant "Old Building," and the technical session was held at the Engineers Club of Washington, Inc. The technical speaker, Jack Ogden, Fisher Body Division, General Motors Corp., made an excellent presentation of resistance welding in the automobile industry. Mr. Ogden showed slides of the intricate welding equipment as built by the welding department for production work. This equipment is built around a standard welding frame and designed by their maintenance department to meet their own needs. His closing remarks were on oxyacetylene and arc welding on the production lines.

It is with great regret that the Washington Section reports that their secretary Bernice M. McPherson has been confined to the hospital due to an automobile accident.

Western Massachusetts

The Gilbert-Barker Co. in West Springfield, Mass., was host for the April meeting of the Western Massachusetts Section. Following a dinner in the plant cafeteria, members and guests of the Section heard Dr. Hallock C. Campbell of the Arcos Corp. lecture on "Recent Developments in Stainless Steel Welding."

One of the main points of Dr. Campbell's talk was that increasing the chromium equivalent in stainless welds increases the amount of free ferrite and thereby decreases tendency to crack. At the same time tensile strength and ductility are improved. Ferrite does not seem to markedly affect corrosion resistance nor does it impair low temperature impact properties.

Dr. Campbell also reviewed three means of remedying intergranular corrosion in welded stainless steels.

Following the talk a demonstration was given of stainless welding techniques. Joseph Tinsman, Quality Control Engineer at Gilbarco, also informally demonstrated some of the heavy-duty spot-welding equipment in the plant.

Wichita

A buffet supper, plant visit and technical meeting were all enjoyed by the members of the Wichita Section on April 9th at the Cardwell Mfg. Co.

A. E. Gander, Technical Sales Engineer of the Air Reduction Sales, Kansas City, Mo., gave an extemporaneous presentation on the subject "Aircomatic—A Gas-Shielded Metal-Arc Welding Process."

E. A. Bussard, Chief Process Engineer, The Coleman Co. Inc., Wichita, spoke on the aims and objects of the A.W.S. and about research and development work sponsored by the A.W.S. The subject was more completely developed by other prominent members of the industry.

Worcester

The April 25th meeting of the Worcester Section was held at the Tower House, with 68 members and guests present. This meeting was Ladies Night.

Following a cocktail hour at 6:00 P.M. dinner was served at 7:00 P.M. Favors were distributed to the ladies, and several attendance prizes were drawn during the course of the meeting. A report of the Auditing Committee was read and approved. The results of the election of officers for the coming year were announced by Chairman C. Myron Burnett. The elected officers were:

Chairman, William L. Walker; *1st Vice-Chairman*, Clifford H. Murray; *2nd Vice-Chairman*, John F. Kenney, Jr.; *Treasurer*, Robert G. Jamieson; *Secretary*, Wesley A. Proctor, and *Directors*, George D. Wilson, Roger W. Moore, Ralph H. Holmes, Joseph H. Polaski and Robert E. Smith.

Past Chairman Ernest Adams presented a Past Chairman's pin to the outgoing Chairman C. Myron Burnett.

A professional vaudeville show followed the meeting along with an amateur talent show with various members taking part. The evening concluded with dancing.

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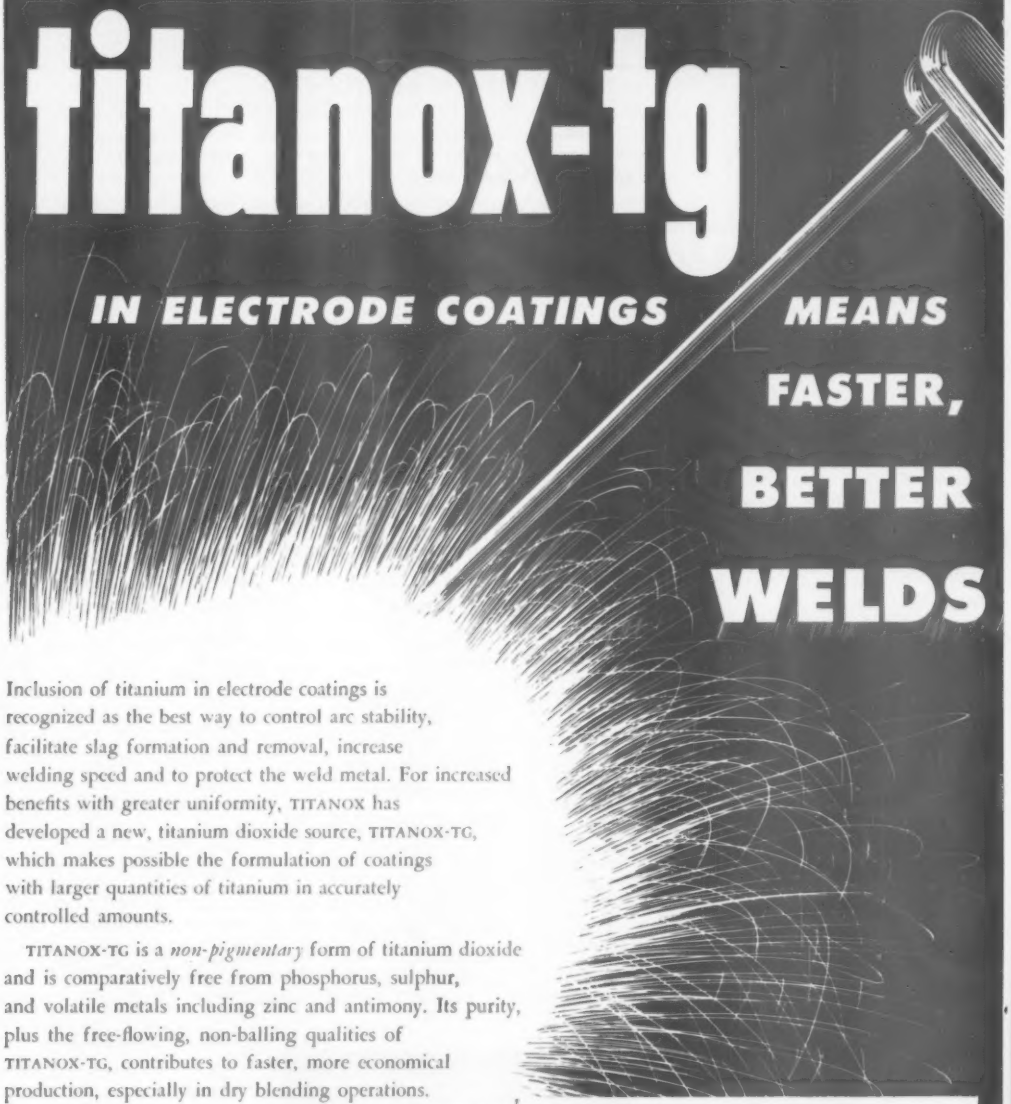

Inclusion of titanium in electrode coatings is recognized as the best way to control arc stability, facilitate slag formation and removal, increase welding speed and to protect the weld metal. For increased benefits with greater uniformity, TITANOX has developed a new, titanium dioxide source, TITANOX-TG, which makes possible the formulation of coatings with larger quantities of titanium in accurately controlled amounts.

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April 1 to April 30, 1951

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Dail, L. R. (B)
Meyers, M. L. (B)

BOSTON
Fluke, W. E. (B)
McGlew, Hugh E. (B)

CHICAGO
Clark, James B. (C)
Ivers, Edward E. (C)
Zahumensky, Edward J. (C)

CINCINNATI
Brinkman, Herbert C. (B)

CLEVELAND
Brotzman, P. H. (B)
Sashko, Paul A. (B)

COLORADO
Longo, Phillip (C)
Weeks, J. T. (B)

COLUMBUS
Henninger, Ray L. (C)
Vagi, Julius J. (B)

DALLAS
Carter, W. Z. (C)

DAYTON
Cochran, H. (B)
Heller, George E. (D)
Long, Harold (B)
Long, Orlan (B)

DETROIT
Gugliari, Rudolph (B)
Hill, Paul J. (D)
Purdie, S. Bruce (B)
Wolfbauer, Michael H., Jr. (B)

HOUSTON
Albrecht, August C. (C)
Clay, Walter L. (C)
Collier, Boyd T., Jr. (B)
Glameyer, W. A. (C)
Granade, E. A. (B)
Muckley, Harold J. (B)
Taylor, Ewin W. (C)

LONG BEACH
Harkins, Frank G. (A)

LOS ANGELES
Buist, B. W. (B)

LOUISVILLE
Thro, Arthur (C)

MAHONING VALLEY
Barefoot, J. R. (B)
Bodenheim, F. A., Jr. (B)
Carleton, C. H. (B)
Craig, Emmet (B)
Deffenbaugh, J. F. (B)
Dunlap, Leo D. (B)
Williams, A. L. (B)

MARYLAND
Donovan, G. Robert (C)
McCubbin, Charles S. (B)

MICHIANA
Schmuldt, Karl H. (B)

MILWAUKEE
Bammeter, Elmer (B)
Mulder, A. C. (C)

NEW JERSEY
Blair, H. Stirling, Jr. (C)
Kearns, R. M. (B)
Korda, Edward J. (B)
Lyon, Victor H. (B)
Merritt, John O. (B)

NEW YORK
Gleicher, Alfred (B)
Grunthaler, George H., Jr. (C)
Herman, Anthony (B)
Hughes, E. Thomas (C)
Pinson, Julius N. (C)
Severs, J. Fredric (B)

NIAGARA FRONTIER
Brown, Andrew J. (B)
Collins, John Francis (C)
Klotz, J. (C)
Kluge, F. (C)
Livingston, R. (C)
McNall, F. M. (C)
Phillips, C. (C)
Rogers, Herbert (C)

NORTHWEST
Carnes, Eugene (C)
Halleen, E. A. (B)
Jordan, Mathew F. (B)
Parkinson, L. A. (C)

PASCAGOULA
Costello, Dan (C)

PEORIA
Anker, Raymond H. (C)
Bachtold, Herman (C)
Bahr, Russel F. (C)
Fidler, Lewis (C)
Hulvey, Stacy (C)
Palumbo, John G., Jr. (C)

PHILADELPHIA
Blessing, Reuben C. D. (B)
Brill, Warren E. (B)
Dezwol, Leon (B)
Filippi, John A. (B)
Galambos, H. A. (B)
Galambos, Paul (B)
Meixell, Veryl (C)
Raiguel, William (B)

RICHMOND
Boyd, Harold C. (B)

ROANOKE
Pittman, D. H. (C)

ROCHESTER
Bonfiglio, C. P. (C)
Smith, Robert (C)
Smith, Sheldon (C)

SAGINAW VALLEY
Trussell, A. J. (D)

SALT LAKE CITY
Chamberlain, Lamar E. (B)
Despain, Leo (B)
Evans, John H. (B)
Hulbert, Frank A. (B)

SAN FRANCISCO
Franklin, R. E., Col. (B)

SUSQUEHANNA VALLEY
Batten, Andrew C. (C)

SYRACUSE
Connolly, J. E. (C)
Cummings, L. S. (C)

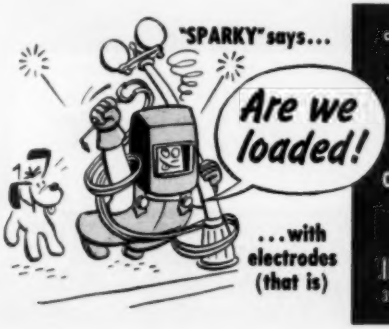
TULSA
Thayer, William W. (B)

WASHINGTON
Hayase, Masashi (C)

WESTERN MICHIGAN
Boulware, J. E. (B)
Tobey, Thomas J., Jr. (B)

WORCESTER
McGrath, Harold (C)

NOT IN SECTIONS
Davis, Bernis (D)
Lockhart, Bruce G. (D)
Mayfield, Bill (D)
Pouchet, Mr. (B)
Remmer, Jorgen (B)
Shaffer, Keith C. (D)
Whalley, Raymond Barker (B)



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NEW YORK
Milligan, R. (C to B)

ROCHESTER
Gregg, Arthur T. (C to B)
Ecklund, Paul A. (C to B)

WESTERN MICHIGAN
Van Loo, Carl (C to B)

WELDING RESEARCH COUNCIL

of the Engineering Foundation

Sponsored by the American Welding Society and American Institute of Electrical Engineers American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers

Supplement to The Welding Journal, June, 1951

Current Welding Research Problems

The purpose of this compilation is to provide University Research workers with a list of current welding research problems and to provide Project Committees with suggestions as to the needs of Industry. These suggestions have come largely from Industry

SOME of the problems are not suitable for University workers because of limitations of facilities, time or money. If any University wishes to undertake research work on any of these problems it is suggested that they first contact the central office of the Welding Research Council, 29 W. 39th St., New York 18, N. Y.

The Council will assist in the formulation of the problem in supplying specimens that may be needed and grants-in-aid on approved projects.

INTRODUCTION

Some 15 years ago the Engineering Societies created, under The Engineering Foundation, an organization now known as the Welding Research Council, to initiate, encourage and conduct research work on the complex problems involved in the fabrication of structures by welding.

The complexity of the problems is such that all branches of science are involved. The University Research Committee of the Council encourages researchers in the fields of pure science, as well as applied science, to carry out research work on some of these problems.

Affiliation with these activities provides the university and the research worker with unusual opportunities for recognition of accomplishments.

A conference of University Research Professors is held once a year, during the time of the National Metal Congress and Exposition. The Council annually makes available sufficient funds to pay for the railroad and pullman expenses of the professors who attend, with an upper limit of fifty dollars to any one professor or research worker. There is thus provided an opportunity for a university research worker to discuss his problems with leaders of industry and with other research workers in the field.

Through close connection with the AMERICAN WELDING SOCIETY opportunity is provided for the presentation of a completed piece of research in the form of a paper at the Annual Meeting of the SOCIETY, which also takes place during the time of the above-mentioned Congress and Exposition. Even though such a paper may not be presented, an opportunity is provided for its publication in a medium which reaches scientific workers throughout the entire world.

In order to stimulate such research the Welding Research Council presents an outline of current welding research problems.

This list represents a framework of research into which the University worker can easily fit his own activities without prejudice to either their independent character or fundamental nature. At the same time, however, he can use his inventive ingenuity on types of problems which, because of their value to industry have a direct influence in raising our standard of living.

The problems listed here are not meant to be comprehensive or exclusive, but rather to suggest the kind of problems toward which the Welding Research Council wishes to direct interest.

While in many cases there has been an effort to refer to work completed, or in progress, on each problem

This report was compiled by Welding Research Council of the Engineering Foundation, 29 W. 39th St., New York 18, N. Y., March 1951.

listed, it should go without saying that any contemplated research should be preceded by an intensive survey of the past and present investigations on the subject under consideration.

In order to facilitate the compilation, the suggested problems have been arranged according to particular fields of research, and have been divided among the following selected headings:

I. Welding Physics and Chemistry.
II. Metallurgy.
III. Mechanical Properties and Testing.
IV. Structural Studies.
V. Resistance Welding.

When going over the suggested problems the University research worker will realize that many of these problems may be studied without knowledge of the welding process itself and without having welding equipment. Others may require the procurement of welded specimens, and payment of expenses. The Welding Research Council will assist by supplying specimens that may be needed and by grants-in-aid on approved projects. However, it is imperative to make plans well ahead of the time at which the research can be started, because of unavoidable delays in delivery of specimens and appropriation of money. Also, the planning should cover as many phases of the problems as feasible, in order to insure that individual projects may contribute to a unified picture of the problem as a whole. A comprehensive and adequate investigation of any problem frequently requires a series of student investigations, properly integrated and coordinated by an interested and enthusiastic professor. The publication of progress reports of which the professor is co-author, tends to rouse the interest of representatives of industry and to accord recognition to the university and the professor.

I. WELDING PHYSICS AND CHEMISTRY

Research in the physics and chemistry of welding falls into two categories:

1. Research on welded products.
2. Research on welding processes, or welding operations.

This list of Suggested Research Problems in Physics and Chemistry is subdivided into these two classes. It has been compiled partly from previous lists and partly from new suggestions. In a few instances, several collaborators have sent suggestions for research on the same subject. To preserve the outlook of each collaborator, each suggestion has been included in the list.

Basic to most research on welding operations and welded products are the thermal constants of commercial metals at high temperatures. The compilation of a table of constants and coefficients for commercial metals up to arc temperatures is suggested as a research problem of the first importance. Unfortunately, many of the thermal data for the table have not been determined. Consequently, researchers on thermal studies of welding are handicapped at the outset.

Suggestions for Research on Welded Products

(Refer to the separate sections on "Structural Studies" and "Mechanical Properties and Testing" for additional suggestions.)

1. Determination of the magnitude and distribution of stress in welded joints, particularly in pipes and fabricated pipe turns.

This problem is, of course, very important and is not by any means limited to welded structures. A fundamental study of methods for studying stress magnitude and distribution would be a large task. A great deal has already been published on this problem and, also, the related question, "Do so-called stress relief treatments actually relieve stresses?" A specialized article dealing with the application of available information on the subject to welded structures would be useful. In order to have any real value, an article of this kind would have to be prepared by a highly qualified specialist in this field. A mere collection of abstracts, or literature reviews, would have little value.

2. The application of the theories of elasticity, plasticity and creep to welded joints.

3. A theoretical and experimental study of the resistance to high velocity application of stress, of different weld metals and combinations of plate and weld metal.

4. The re-enforcement of structures under load. The development of the conductivity formulas and graphs in Chapter 2 of the 1950 Edition of the *Welding Handbook* in terms familiar to structural engineers, with special emphasis on equation 5, page 64, and on the depth of the overheated zone.

5. Corrosion of Weldments. The particular aspect of corrosion phenomena brought about by welding has been studied quite extensively, but no satisfactory theory has been formulated. This is due undoubtedly in part to the complexity of the phenomenon, but a clearer picture is believed to be possible, if corrosion research were undertaken without regard to an immediate practical solution of the problem. The following fundamental aspects are proposed:

(a) Influence of metal dissimilarity.
(b) Influence of metallurgical structures.
(c) Influence of stress.

This last aspect has particular importance, because the process of welding implies the production of residual stresses.

The rusting of welds in mild and low-alloy steels, in the air and submerged, should be studied to determine whether the same principles apply to bare or slag-covered weld metal as to bare or scaled plate.

Suggestions for Research on Welding Processes

Each major welding process has many subdivisions. For example, gas welding may be subdivided into air-acetylene welding, oxyacetylene welding, oxyhydrogen welding and pressure-gas welding. Likewise cutting may be subdivided into oxygen cutting, lance cutting, powder cutting, and arc cutting, each of which, in turn, has numerous subdivisions. A researcher familiar with any of the processes knows that he can ask questions about the physics and chemistry of each process that experts cannot answer. Frequently the researcher has the mental and experimental facilities the expert lacks to approach the problems posed by his process. For this reason it is believed that, if the researcher will familiarize himself with the details of any given welding process, and break down the process into its physical and chemical variables and occurrences, the research problems that he can attack will suggest themselves to him naturally.

(*A*) *Resistance Welding* (refer to the separate section on "Resistance Welding").

(*B*) *Arc Welding* (refer to bibliography being prepared by A.I.E.E. Subcommittee or Arc Research, R. C. McMaster, Chairman). 1. Mechanism of Metal Transfer in the Welding Arc. Development of instruments and techniques for the observation and measurement of metal transfer in the iron-iron welding arc, a classification of types of metal transfer and evaluation of factors controlling metal transfer.

2. Steady-State Properties of Heavy-Current Welding Arcs. Evaluation of temperature in the arc column, potential drops at the surface of the electrodes, current density in the arc column and at the electrodes, potential gradient in the arc column, heat produced in the arc column and at the surfaces of the electrodes with arc current, atmosphere, pressure, metal vapor and coating constituents as parameters.

3. Arc Stability and Methods of Stabilizing Arcs. Study of the various stabilizing circuits with parameters of: voltage gradient in the arc column, ionization potential of the arc atmosphere, current density and arc current, electrode materials and configuration, thermal time constant of the arc atmosphere, the recombination and diffusivity of electrons and ions in the arc atmosphere, the supply of vapors and gases from electrodes and coatings.

4. Influence of Atmosphere and Coating Ingredients Upon the Properties of the Welding Arc. Determination of the fundamental characteristics of the welding arc as functions of various atmospheres, especially their effect on the arc heat and heat transfer to the electrode and work.

5. The Influence of Metal Conditions Upon the Welding Arc. The characteristics of the welding arc as functions of: ionization potential of the metal vapor, the vapor pressure and rate of vapor production, the melting and boiling points, the thermal conductivity, the heat of evaporation, the temperature of the metal, and the geometry and cooling characteristics with refractory and readily vaporized electrodes.

6. Heat Transfer Mechanism Between the Arc and Metal Surfaces. Study of the electrode potential drop region to within a micron of the surface as to physical state, power converted into heat, heat-transfer laws, melting and vaporization of electrode metal, state of particles in the arc atmosphere at the electrodes and electrical properties of this region. Also the heat transferred to the electrodes by conduction, convection, diffusion and molecular dissociation.

7. High-Current Phenomena in Arcs Between Electrodes Other Than Carbon. Volt-ampere characteristics at currents in the positive-slope region, anode and cathode drop characteristics, determination of the current-carrying mechanism, current density and potential distribution in the main arc stream and in the anode and cathode drops, determination of the percentage of heat dissipation by radiation, convection, conduction and molecular dissociation, determinations of temperature distribution in the arc stream, determination of the effect of various atmospheres and pressures on the arc, the effect of magnetic stabilization.

8. An extension of Froome's cathode-spot current-density study to steady-state arcs. Fundamental information on spot mechanism could be obtained with cathode-ray and Kerr cell photographs.

9. Theoretical Treatment of Electron Emission by a Very High-Temperature Plasma Under the Influence of an Electric Field, as Basis for a Reasonable Theory of the Cathodic Processes in Metal Arcs. Work should include investigation of temperature concept. Essentially a theoretical investigation, the results of which then could be checked by comparison with experimental data known.

10. Development of a method of measuring instantaneous arc temperatures with a view toward better understanding of arc stability.

11. Ionization of the arc. An exploration of the nature of the ions contributing to the conduction in arcs of various types would be valuable. The most attractive problems are:

(*a*) Source of charged carriers, whether electrode, base, coating or shield.
(*b*) Influence of the shield on the discharge.
(*c*) The nature of arcs using various metal electrodes.

A great deal of work has been done, or is planned, but the field is so vast that parallel researches appear desirable.

12. Distribution of energy in the welding arc. A quantitative measurement of the energy contained in and distributed by an arc deserves further investigation. The energies used in melting electrode, melting plate and radiated to the atmosphere and the manner in which they are affected by current, travel speed, plate temperature and coating should be determined.

13. A study of the relative influx of air into covered electrode arcs as a function of travel speed, arc length and weaving motion.

14. What causes the arc force pushing back against the electrode? Is it related to the gas content of the

metal? Is it found with nonferrous alloys and in inert gas-arc welding and in submerged arc welding?

15. An oscillographic study of striking an arc. A quantitative method is required for determining ease of arc striking with an investigation of the following variables: a. c. versus d. c., superimposed high-frequency striking current, open-circuit voltage, composition of atmosphere, nature of striking surface, composition of coating on the electrode.

16. Electric conductivity of welding slags up to arc temperatures with particular reference to submerged arc welding.

17. An exploration of arc action, including visible length, short circuits and type of metal transfer, over wide ranges of current and voltage. The well-known standard covered electrodes should be studied as well as submerged arc welding. For submerged arc welding the electrode might be immersed in a crucible of liquid flux above the metal before current is turned on. Current-voltage determinations might be made with increasing gap between metal and rod (see paper by C. E. Jackson and A. E. Shrubsall, THE WELDING JOURNAL, May 1950, pages 231-s to 241-s).

18. Problems in inert gas-arc welding. (*a*) Effect of Metal Vapor in Inert Gas-Shielded Arcs. How much vapor exists in the arc plasma and what is its effect on voltage gradient. If possible, develop theory predicting observed values.

(*b*) Arc Voltage. Relative portions of arc voltage due to plasma, cathode region, and anode for wide variety of currents, current densities, materials, and shielding gases. This study would provide a basis for further theoretical development of the atmospheric arc and would lead to better understanding of wire burn-off and plate melting in welding.

(*c*) Determination of Deionization Time in Atmospheric Arcs. Variation of time with gas shield, current and other variables.

(*d*) Effect of Gas Shield on Transfer Phenomena Using Bare Wires. Motion pictures of transfer and theoretical deduction of mechanism involved to reduce spatter in welding.

(*e*) Arc Radiation Losses. Measure radiation loss from inert gas-shielded arcs.

(*e*) Arc Radiation Losses. Measure radiation loss from inert gas-shielded arcs.

(*f*) The effect of H_2 and H_2O additions to argon and helium on the stability of the inert gas-shielded arc with thoriated tungsten, aluminum and stainless steel electrodes. The object of the research would be to demonstrate the effect of known percentages of H_2 and H_2O in the arc atmosphere on the ease of striking an arc and on its steadiness using alternating current and both polarities direct current with and without superimposed high frequency.

19. Cooling rates. There have been very extensive studies in this field from the viewpoint of weldability. There are, however, some problems which require further study.

(*a*) Influence of high currents and speeds on cooling rates and also on weld contours.

(*b*) Extension of data and methods of analysis to other metals, such as stainless steel and aluminum.

20. Slag-metal relationships in welding. A study should be made of the oxygen and manganese contents of slag and weld metal for submerged arc welding and covered electrode welding. The object would be to determine the degree of deoxidation of various weld metals and the variables affecting deoxidation.

(*C*) *Gas Welding and Cutting.* 1. A study of the variation of the composition of the weld metal as a function of the flame adjustment in oxyacetylene welding.

2. A study of the causes of sparking in gas welding with mild steel and low-alloy steel rods.

3. A study of the origin of drag lines in oxygen cutting and the effect of nonturbulent oxygen jets.

4. A study of the characteristics of flames from different welding torch tips as a function of gas pressure. The characteristics to be studied are shape of flame, radiation from flame and velocity of gas for various gas-to-oxygen mixture ratios.

(*D*) *Pressure Welding.* 1. The pressure welding of commercial metals, similar and dissimilar combinations, should be studied to determine the effect of the following variables:

(*a*) Degree of plastic deformation required to secure a weld.
(*b*) Effect of the rate of application of pressure.
(*c*) Role of recrystallization, if any.

II. METALLURGY

Since welding is essentially a metallurgical process, the field of metallurgy is expected to supply most of the information needed for successful welding. The word successful means producing weldments free of the three following defects: (1) cracks, (2) porosity (or nonmetallic inclusions) and (3) deterioration of usable characteristics of the material of which ductility is the most common and the most widely required. Each of these defects is by itself a problem of considerable magnitude, and it is feasible to study them separately, bearing in mind that in many instances they are interdependent to a great extent. Thus, cracking is perhaps the most alarming defect in welding, but considerable loss in ductility may be potentially as dangerous because cracking may then occur under conditions which are considered safe for the nonwelded material. Whatever phenomenon is being considered, the influence of the following factors appears immediately.

1. Base metal.
2. Weld metal.
3. Degree of restraint during welding.
4. Treatment before and after welding, both mechanical (for example, peening) and thermal (for example, the so-called stress-relieving treatment).

5. The welding process.

Each of these factors is defined in turn by several more specific and more fundamental variables. Thus, base and weld metal may be considered from the point of view of structural, phase or chemical changes. The degree of restraint may be characterized by geometry, state of stress or amount of cold work, etc.

What is basically important is to reduce all of them to as many independent variables as possible. This is by no means an easy problem, and the value of a particular investigation is largely dependent on how successful it has been in varying only one factor, while keeping the others as constants.

Much of the metallurgical work performed in the field of welding research has been based on the more thoroughly investigated fields such as the heat-treatment of steels. This is true of the many studies of the relationship of hardenability to weldability and the general studies relating weldability and composition.

Although the investigator has been hampered in his attempts of simplifying experimental procedures, many investigators have shown their ingenuity in design and execution of test programs. In the following section, will be mentioned some of the general contributions to the field of welding metallurgy and comments will be included, regarding many problems which have not been investigated sufficiently to produce a generally accepted explanation.

(*A*) *The Welding of Steel*

A number of articles have covered the general problem of welding plain carbon and low-alloy steels, the materials generally used for investigations of the weldability problem. Preliminary discussions have appeared in the *Research Supplements* to THE WELDING JOURNAL, for example, Vol. 24, June 1945, page 313-s and Vol. 28, June 1949, page 246-s. The third edition of the *Welding Handbook*, page 79, contains a rather extensive chapter on the "Fundamentals of Welding Metallurgy."

A rather extensive effort is under way in the preparation of a Monograph on Weldability. This monograph will present a general survey of the metallurgy of welding together with tables of recommendations for the welding procedures for many specified grades of steel covering a wide range of chemical composition, thickness and intended uses.

Based on a survey of the information available in welding metallurgy, the following problems are suggested as worthy of further note:

1. There is need for a simple test of weldability which can be correlated with service.

2. Much work still remains to be done on the effects of welding on the notch sensitivity of steel and the reason for the change from ductile to brittle type of failure. It is hoped that future investigations in this field will strive to attack the problem more from a theoretical rather than an empirical point of view. The many investigations in this field and the efforts of the Ship Structure Committee being carried out at several laboratories should be studied before undertaking further work in this field.

3. The studies at Rensselaer Polytechnic Institute and Massachusetts Institute of Technology, as well as some of the aspects of the work at Lehigh University and Battelle Memorial Institute, have been interesting in determining the effect of microstructures on transition temperature. Further investigation of the effects of microstructures produced by the welding thermocycle would be useful if studied from the standpoint of the properties of the structures individually and in the aggregate. An exhaustive study of the role of strain aging in the welding of steel is needed. Preliminary work has been carried out by the University of California.

4. We need to know more about the effect of inclusions and alloy segregation, of cooling rates in the ingot phase, heating time in the slab and rolling procedure on the cracking tendency of weld joints. Although the role of carbon is pretty well established, active individual elements, and elements in popular combinations, have not been fully investigated. Most welding engineers strive for crack-free structures and although much work has been carried out at Lehigh University and Battelle Memorial Institute in this field, many additional related investigations are in order.

5. Further investigation is needed of the role of gases such as hydrogen and nitrogen as well as the effect of residual or tramp alloys in steels on cracking and embrittlement of welds. Any such study would require the re-evaluation of the type of test program which might be used.

6. It would be desirable to prepare a quantitative evaluation of the effect of type of electrode coating on the cracking tendency. This might include a valuation of the performance of slag-shielded and gas-shielded electrodes on the soundness and quality of weld deposits. Little work has been reported relating to the metallurgical reactions between welding slags and molten weld metal.

7. The effect of restraint on cracking tendency has been repeatedly pointed out. Further investigation would be desirable in quantitatively evaluating the effective restraint in one specimen as well as various welded structures. It would be highly beneficial to the investigators in this field if it were possible to quantitatively evaluate restraint. Such an evaluation should provide a reference for correlating the various test pieces and data which have been obtained using various specimens and testing procedures.

8. There have been numerous questions raised regarding the effect of the so-called stress-relief treatment of welded structures. It would be well to investigate these effects in order to have a more fundamental basis for controlling the relief of shrinkage and locked-up stress in welded structures. The question has been raised as to whether furnace stress relieving of plates after they are formed, followed by preheating ahead of

welding, is practically as effective as furnace stress relieving of the entire finished structure.

9. Another problem which is closely related to that of stress relief is that of using preheat in structures which normally are not suitable for furnace stress-relief treatment. Questions have been asked whether preheat and stress relief are supplementary or complementary. As additional information becomes available, it appears that the use of preheat has effects which are more extensive than would be indicated simply by the change in cooling rate in the welding zone.

10. It would be desirable to investigate the relationship of the stability for machining of welded structures which have been furnace stress relieved, fabricated with the use of preheat or fully annealed by heat treatment.

11. Recent studies by the American Bureau of Shipping have led to improved methods of quantitatively measuring the effects of peening. Further studies should be aimed at the evaluation of the effect of peening as far as the cracking tendency, notch sensitivity, dimensional stability, as well as the reduction of distortion.

12. Recent investigation at the University of California has pointed out the effects of cooling rate at relatively low temperatures. This work should be continued in order to determine whether such an effect might apply to welded structures.

13. It would be well to investigate the mechanical properties of the deposited metal using various types of electrodes over a wide range of testing temperatures. This study should be aimed at detecting brittle structure at both high and low temperatures.

14. Many difficulties have been encountered in the welding of low-quality steels containing segregation and laminations. These effects may be traced to gas content or melting and rolling practice. An example of this type of problem would be that of investigating the nature and cause of porosity, particularly at starts and stops, on 4–6% chromium-molybdenum steel welded with mineral and lime ferritic-coated electrodes.

15. Other investigations aimed at the improvement of the welding of particular grades of steel would be desirable. *Example:* Additional work would be useful in studying weldability of cast steels with their generally higher silicon.

16. Further correlation is needed on the welding of heat-resistant materials for gas turbines and jet engines. Such a program should include a study of the efficiency of different welding methods on the properties of the materials involved in these parts for service at elevated temperatures.

17. Little effort has been reported on the over-all effect of composition on the performance of welded structures. Much of the original work at Battelle related to the effect of carbon and manganese. Preliminary work has shown that carbon is probably the most potent element in reducing the weldability of a steel.

18. A quantitative investigation of the recovery of various elements in arc welding would be informative. This should include welding processes other than with coated electrodes and should be aimed at improving the transfer and recovery of some of the materials such as titanium.

(*B*) *Welding of Dissimilar Metals*

1. There is a lack of basic information in the welding of many of the nonferrous metals. This lack of basic information is even more acute in the welding of dissimilar metals. Little quantitative information is available concerning the nature and mechanism of alloy diffusion or pickup and dilution. These problems pertain especially to the resistance welding of dissimilar metals such as:

(*a*) Dissimilar ferrous metals.
(*b*) Dissimilar nonferrous metals.
(*c*) Dissimilar ferrous to nonferrous metals.

A considerable amount of work on spot welding of unlike aluminum alloys has been reported by Rensselaer Polytechnic Institute. Other problems remain such as the spot welding of stainless steel to low plain carbon or hardenable alloy steels.

2. There is also a lack of basic information in connection with (1) the arc welding of clad materials, (2) the arc welding of dissimilar metals and (3) the arc welding facing operations.

3. In addition to the above, information is needed on joints between dissimilar metals as to:

(*a*) Thermal expansion characteristics.
(*b*) Mechanical properties.
(*c*) Effect of elevated temperature on alloy diffusion and the effect of the diffusion on the properties of the joints. This is important in high temperature applications of clad materials, hard facings, etc.

4. Brazing and soldering involve the same general problem as that of joining dissimilar metals. There is also, however, the specific problem of surface tension, more commonly called the tinning property of solders, which requires a fundamental approach. A method is required to measure the tinning properties of various brazing and soldering materials.

III. MECHANICAL PROPERTIES AND TESTING

Many of the problems raised under the heading of "Metallurgy" cannot be properly solved unless the *stress* and *strain* characteristics are correctly accounted for. Further, determination of actual mechanical characteristics of material fabricated into a structure and the change of these characteristics produced by welding are not always shown up by usual tests and testing equipment. Therefore, welding has a large stake in the field of mechanical engineering and testing. Of basic importance for welding is what has been defined as "The Weld Stress Problem."* This is of major

interest in the welding of steel, but the problem extends to all materials and involves both metallurgical and mechanical fields of research. The following covers only the mechanical aspects.

It is axiomatic that failure of a structure must be preceded by plastic flow. In some cases this plastic flow is of such a small amount as to be almost negligible, and in extreme cases, such as failure of a glass jar at ordinary temperatures, no measurable deformation may take place. However, even in this case there is an attempt to plastically deform. The state of stress influences the conditions under which plastic flow can take place. For example, theoretically, balanced triaxial stresses would cause carbon steel to act as a glass jar, i.e., no measurable deformation would take place before failure.

(*A*) *State of Stress*

From the host of information which is beginning to accumulate as a result of research, evidence seems to emerge that states of stress which are not higher than biaxial do not alter appreciably the initiation of plastic flow as compared to the uniaxial tension test. This statement is valid for the applied as well as residual state of stress. The influence of notches and metals dissimilarity is under investigation, but if conditions are limited to the surface, the situation does not appear to be much affected by these two factors. The real problem is, therefore, what happens below the surface. This problem is equivalent to that of a triaxial state of stress, for obviously no triaxial state of stress can exist at the surface.

It is obvious that one of the most important and difficult problems confronting the research investigator is to determine what basic laws govern the elastic and plastic deformation of metals under various conditions. Additional information is badly needed, especially on the following topics:

1. Quantitative data on how much a steel of known conventionally determined physical properties at different temperatures—strength, yield point, ductility—will deform plastically under specific conditions of constraint and speed, intensity and cycles of loading.

2. Determination of the plastic and elastic interaction between base and weld metals having different mechanical characteristics, yield point, ultimate tensile strength and elongation under various external loadings.

(*B*) *Rate of Straining*

The influence of temperature and rate of strain upon the plastic behavior of steels is of fundamental importance. Considerable work has been done along these lines. However, much more data are needed before it will be possible to apply findings to ordinary steel structures. There is evidence that in ferritic steel the total amount of strain before failure is influenced by two factors—temperature and rate of strain. This information should be extended.

(*C*) *Size Effect* (*Rigidity*)

Evidence begins to accumulate slowly that the tendency toward brittle fracture increases as the thickness becomes greater. The word "rigidity" has been used frequently to describe this behavior, and plasticity experts would think probably of the word "triaxiality." Actually neither of these terms seems to be any better than the other, as the true situation is probably far more complex. However, if it were possible to express one situation in terms of another, say rigidity in terms of plate thickness, or the latter in terms of triaxiality, an important step forward would have been made.

(*D*) *Residual Stress*

In order for residual stress to contribute to the failure of a structure it would be necessary for plastic flow to be inhibited to the point that such residual stresses would not be relieved by local plastic deformation. Enough work has been done to show that only under very specialized conditions would it be possible for residual stresses to thus contribute to failure. The important question is, in actual failures do such conditions exist? The fact that several ships have failed under conditions where the imposed loads were very low would indicate the possibility of harmful effects due to residual stresses. The problems therefore are: (1) to determine if the conditions necessary for residual stresses to contribute to failure can actually exist; (2) to quantitatively evaluate the effects, both beneficial and otherwise, of residual tensile and compressive stresses, especially in welded structures; and (3) to determine the actual effect, both on metallurgical structures and on the state of stress of the various stress-relieving processes, including overstressing by hydraulic loading, thermal stress relief, low-temperature stress relief and peening. Some of this work is now being done at various laboratories. The Welding Research Council is to be contacted for further information.

(*E*) *Mechanical Properties of Welded Joints*

The study of the mechanical properties of welded joints has provided important information to the users of welding processes and represents an outstanding contribution to the development of these processes. Fundamental data are still needed in many fields, and the determination of these data can become a gratifying subject for many graduate and undergraduate thesis investigations. The following problems should be considered.

1. Fatigue Studies. While fatigue is at present a problem only under certain highly specialized cases, if

• "The Weld Stress Problem," The Welding Journal, 24 (6), Research Supplement, 313-s to 319-s (1945).

higher design stresses are more widely used, the problem of fatigue becomes more important. The endurance limit of steel is generally a function of ultimate tensile strength. However, there are several proposed methods of increasing fatigue resistance, and these should be studied. Also, fatigue effect on fabricated structures should be more thoroughly investigated. For example, many beams are fabricated by cutting and rewelding standard structural shapes. Fatigue effects on these are as yet unknown. Studies of fatigue in the plastic range are only limited in extent and should be broadened.

2. Test Methods. It is recognized that the conventional physical tests do not accurately reflect the properties of material fabricated into structures. A whole series of weldability tests which attempt to take into account the structural factors have been proposed. None has been widely adopted. A rational test method is badly needed which will enable the behavior of structures to be predicted on the basis of small-scale tests.

3. Theory. Various theories covering the strength of materials have been applied to welded structures. So far, it has been impossible to apply any generalized theory, making necessary lengthy and involved calculations. The various strength theories which have been proposed should be critically evaluated, especially as applied to structures with dissimilar properties of weld and base metal.

4. Specific Problems. There are a number of specific problems which have been referred to the Welding Research Council. These are listed below. In many cases, the broader problems referred to above would automatically involve solution of these individual questions:

(*a*) Determination of the magnitude and distribution of stress in welded joints, particularly in pipe.

(*b*) It is important to determine to what extent plastic straining during the hydrostatic pressure test can be relied upon to impart final shape to a pressure vessel without impairing the mechanical characteristics of the material. This problem is of practical interest, since it has been observed that the metal near the junction circle of the knuckle and crown of a conventional basket (dished or torispherical) pressure vessel head frequently deforms plastically under the prescribed hydrostatic test. Similarly, depending upon the apex angle and the ratio of thickness to shell radius, the joint between the conical head and the cylindrical shell of a pressure vessel deforms much or little under the hydrostatic pressure test. The change of properties produced by the above operation should be studied by one of the methods worked out in connection with the study of weldability, outlined previously under Section II—Metallurgy. It is hoped that a carefully planned and executed test and analytical program will provide a reliable basis for design.

(*c*) The most careful designing of the shell of a pressure vessel may be completely nullified by poorly designed supports. Investigation is desirable as to the proper method of design for saddle, ring and lung supports for horizontal cylindrical vessels; and skirt, bracket and column supports for both spheres and vertical cylinders.

(*d*) Investigation is needed of reinforced manhole openings where the manhole consists of a forged ring butt welded into the shell plate and the manhole cover is attached by stud bolts in the ring.

(*e*) Determination of the concentration of stresses and development of suitable maximum design stresses in vertical vessels having semi-elliptical head and supported on skirts that are attached to the knuckle of the head.

(*f*) The same as above where the vertical vessel has a conical or toriconical head.

(*g*) Correlation of tensile properties of steel plate in a direction at 90° to the plane of the plate, with the permissible design stress of lap or fillet weld joints subjected to tensile loads in the same direction. This is of interest in connection with proper evaluation of fillet and lap weld joints in applications where stresses in the direction described above are involved, such as in certain types of nozzle, head, staybolt and tube sheet connections to pressure vessels, and in some structural and similar joints.

(*h*) Thermal transient stresses in pressure vessels submitted to sudden changes of temperature.

(*i*) Application of sonics and supersonics to nondestructive testing of weldments.

(*j*) Although numerous proposals have been advanced for the nondestructive testing of flash and spot welds, there is a place for more simple and reliable methods, if these can be developed.

IV. STRUCTURAL STUDIES

Most of the pioneering work in welding has started in the structural field. This work has been concerned with welded joints and welded connections as applied to existing types of structure, and has resulted in a substantial improvement and economy of the structural design. In some cases, however, the results were less gratifying especially where the increased rigidity of welded structures had been obtained by increasing the thickness or accumulation of the weld deposit. The fundamental problem of local rigidity has been discussed previously in Section III under the heading of Mechanical Properties and Testing. Whatever solution is accepted for this fundamental problem, adequate methods of design must be provided. Briefly stated, the problem is to design a structure in which greater load-carrying capacity and greater stability can be achieved without increasing locally the thickness of elements or accumulating a greater amount of weld. This problem can be studied by one of the following means:

1. Model studies on frame and plate-like structures.
2. Design of new types of section for welding.
3. Testing of full-scale structures.

In addition to this fundamental problem, many immediate problems await solution, such as:

4. Transfer of stress at end of partial-length cover plates.

5. Design of spot-welded joints. This problem involves the determination of proper size, spacing and distribution of welded spots for the purpose of achieving maximum efficiency in static and fatigue loading.

6. Influence of distortion produced by welding on the stability of flanges and webs in large plate girders.

7. Stress distribution in full-scale welded structures. Experimental and mathematical analysis of stress distribution in beam and column connections and in built-up girders should be made in order to deduce reliable design formulas.

8. Influence of residual stress on the stress distribution in statically indeterminate structures. More specifically, it is important to determine whether the early plastic flow resulting from the presence of residual stresses is beneficial in redistributing the effect of overloading.

9. Increased knowledge is needed of shrinkage stresses from the point of view of controlling, minimizing and correcting distortion.

10. Significance of fatigue in weld design with the idea of improving the strength of structural members when subjected to cyclic loading. These improvements can be brought about by more favorable geometry or by more favorable metallurgical conditions at the point of initiation of fatigue failures.

11. The reliability of engineering calculations appertaining to structural strength with the idea of avoiding brittle fractures.

12. A study of the relative effects on weld quality (particularly notch sensitivity) of weld metal stronger than the parent plate, weld metal weaker than the parent plate and weld metal of substantially the same strength as the parent plate.

13. Most desirable methods of welding reinforcing bars used in reinforced concrete.

V. RESISTANCE WELDING

Resistance welding embraces the processes of spot welding, seam, projection, flash, upset and percussive welding. A detailed description of each of these processes and the equipment necessary thereto is contained in the *Welding Handbook* published by the AMERICAN WELDING SOCIETY.

The research problems are rather arbitrarily divided into: (*A*)Electrical and Physical Characteristics, (*B*) Metallurgical Effects, (*C*) Physical Properties and Tests. However, there is considerable overlapping among these groups.

(*A*) *Electrical and Physical Characteristics*

1. Determine the relationship between electrical contact resistance and the current, pressure temperature and surface preparation of the metal welded. An additional phase of this problem involves the thermal contact resistance and the same variables. Another problem would be to investigate the possibility of the application of spreading resistance techniques to spot welding of copper.

Researchers are referred to technical reports published by Rensselaer Polytechnic Institute and Johns Hopkins University on this subject.

2. In flash welding study the relationship of the variables flashing speed, current, current cutoff and pressure. Thorough instrumentation is required, including a recording watt meter and recording oscillograph.

3. An investigation of electrical resistance brazing including current density, pressure, temperature and heating time for specific brazed areas, comparing results with conventional furnace heating. Some limitations are encountered in making large area joints by furnace brazing, and this tendency should be studied in resistance brazing.

4. Study the effect of postheating on the fatigue strength of spot welds. Postheating is one method that holds possibility of increasing the comparatively low fatigue strength of spot welding joints.

5. Determine the effect of the shape of the abutting ends of upset butt-welded rods upon the physical properties of the joint. Considerable change in properties has been found with different end preparations, particularly on rods containing higher carbon contents up to about 0.65%. Different preparations could include flat, chisel point or cone points.

6. Seam welding speed. The speed with which a seam weld can be made is proportional to the frequency of the a.-c. power supply. Each wave produces a weld nugget and above certain speeds unwelded areas appear between these nuggets, resulting in lack of pressure tightness. It may be possible to devise other electrical systems without this defect.

(*B*) *Metallurgical Effects*

1. Investigate the metallurgical effects of welding dissimilar metals. Work with Monel, nickel, Inconel and chrome nickel stainless grades should be considered.

2. Spot welding of copper. This process depends on proper electrodes which will not deteriorate in contact with the copper workpieces. It may be necessary to generate additional heat within the electrodes so that the fusion temperature may be reached in spite of the high thermal conductivity of the copper workpiece.

3. Spot welding of silicon bronze, silicon brass and red and yellow brass to determine optimum welding conditions. Contact resistance must be carefully measured and the application of electron defraction equipment might be useful.

4. A study of the effect of welding conditions upon the mechanical properties and corrosion resistance of spot-welded aluminum alloys.

5. Investigation of the effects of spot welding on steels coated with low melting point metal, e.g., galvanized steel, tin plate, terne plate, gilding metal.

6. Effect of metallurgical quality (deoxidation,

grain size, surface finish) on the spot weldability of steel. Again surface contact resistance is of prime importance.

7. Basic studies of the properties of resistance-welded titanium.

8. Micro investigation of the fusion line of flash and upset butt-welded joints for decarburization, or other variations in structure produced by variations in the welding conditions. Anomalies in properties of these welded joints have been ascribed to local variations in the structure at the fusion line.

(C) *Physical Properties and Tests*

1. Spot welding. Valuation of the effects of residual stress in spot-welded assemblies. Stress concentrations of a severe order exist in spot welds and have an influence on the properties.

2. Development of nondestructive tests and evaluation methods for resistance welds.

3. Effect of fiber distortion in flash and upset butt welding. A study could include a cold-rolled or drawn material with pronounced longitudinally oriented structures plus the same material in the normalized condition.

The Hardness of Oxygen-Cut Surfaces and Their Softening by Heat Treatment*

by G. Kritzler and H. Thier

THE steels shown in Table 1 were cut with an oxygen torch. The cut surfaces were tested for hardness with a 2.5-mm. ball under a load of 30 kg. The readings varied considerably because the surface consists partly of fused material and partly of unfused material, both of which have been carburized during cutting. Although no preheat was used, no cracks were found. Spectrochemical analysis showed that silicon and manganese were absent in a zone 0.002 to 0.004 in. deep below the cut surface. On the other hand, the copper content of the edge zone was the same as the plate, while the molybdenum content was three to four times that of the plate. The carbon content of a layer 0.004 in. thick cut from the 0.26 C St52, 1.73 in. thick, was 0.70%, as determined by a steelworks laboratory. The increase in carbon content of the surface accounts for the higher hardness of normalized cuts compared with unaffected plate.

Preheating to 400° F. before cutting lowered the hardness of Steel MI to 170–194 Brinell. Preheating to 800° F., on the other hand, resulted in 163–218 Brinell and a wide heat-affected zone despite faster cutting speed.

A number of experiments were made to reduce the hardness of the cut surface by the use of multiflame burners preceding or following the torch. Satisfactory results could not be obtained. Reheating the cut surface with a suitable burner after cutting was found to be a dependable means of normalizing. Slow speeds could be used for heavy plates of plain carbon steel, while high speeds of reheating torch motion had to be used with light plates of alloy steel to avoid overheating.

* Abstract of "Zunahme der Härte an Brennschnittkanten und ihre Beseitigung," published in *Stahl u. Eisen.* **71,** 119–124 (Feb. 1, 1951). Condensation of a doctor's thesis at Braunschweig Technical College in 1944. A research report of the Maschinenfabrik Buckau R. Wolf A.G. at Neuss-Grevenbroich. (Abstracted by Dr. G. E. Claussen.)

Table 1—Hardness of Cut Surfaces

Designation	*Thickness, in.*	*Chemical composition, %*							*Brinell hardness*			
										Oxygen-cut surface		
		C	*Si*	*Mn*	*P*	*S*	*Cu*	*Others*	*Normalized; not cut*	*As-cut*	*Torch normalized*	*Furnace normalized*
MI	1.38	0.14	0.31	0.52	0.017	0.024	0.21	...	128	218	174	167
MII	1.61	0.24	0.16	0.54	0.024	0.033	0.25	...	138	285	167	180
St 42.21	1.34	0.17	0.32	0.45	0.014	0.029	0.52	...	129	229	164	177
St 50.11	0.71	0.19	0.38	0.89	0.021	0.028	Trace	0.11 Ni	153	272	187	180
St 60.11	3.15	0.48	0.18	0.46	0.032	0.016	Trace	...	185	339	266	244
High carbon	1.10	0.79	0.33	0.83	0.014	0.012	0.17	...	242	611	363	292
St 52	0.79	0.21	0.54	1.35	0.014	0.033	0.37	...	159	260	235	215
St 52	1.10	0.20	0.58	1.38	0.017	0.019	0.26	...	169	383	229	207
St 52	1.58	0.23	0.39	1.04	0.012	0.028	0.44	0.20 Mo	156	265	174	170
St 52	1.73	0.26	0.33	1.00	0.032	0.039	0.54	0.10 Mo	167	285	207	166
Square billet	9.45	0.33	0.28	1.01	0.018	0.023	0.20	1.16 Cr 0.14 Ni	248	592	415	384
Round bar*	1.00	0.42	0.77	0.68	0.012	0.004	0.15	1.73 Cr 0.17 Mo 0.17 Ni	313	611	383	383

* Disk cut from a bar 7 in. in diameter.

Strain Aging of Pressure Vessel Steels

This report has been prepared under the supervision of an advisory panel consisting of G. V. Smith, Chairman, S. Epstein, B. G. Johnston and H. K. Work under the sponsorship of the Materials Division of the Pressure Vessel Research Committee, Welding Research Council

by Helmut Thielsch

SUMMARY

STRAIN aging is a phenomenon long associated with the fabrication of mild steels for pressure vessels. It is initiated by cold work and can, therefore, occur after any moderately severe forming operation such as bending, straightening, shaping, deep-drawing, or stretching conducted at temperatures below the critical range of the steel. Its more practical manifestations comprise an increase in strength and hardness coupled with a reduction in ductility and toughness, which can result in serious embrittlement of the steel. These changes in properties occur spontaneously with time after cold working.

The phenomenon has been intensively investigated by metallurgists and physicists interested in both theoretical and practical aspects, but much yet remains to be learned. This report attempts a straightforward interpretation of strain aging in terms acceptable to the average engineer without specialized metallurgical knowledge. Emphasis has been placed on the more practical aspects of the phenomenon.

Decreased ductility, as a result of strain aging, can be a handicap to fabricating operations; the degree to which it can be tolerated is the limit beyond which cracking of the plate occurs during subsequent cold forming. The degree to which decreased toughness, resulting from strain aging, can be tolerated without impairing the usefulness of the vessel in subsequent service is less readily defined. Certainly, many pressure vessels are performing satisfactorily despite the fact that they may have suffered a loss of toughness as a result of strain aging. The incidence of reported service failures is not high. It can only be suggested that the same criteria probably apply to both critical pressure vessel applications and vessels destined for service at subzero temperatures.

Strain-aging embrittlement may be successfully circumvented by using specially killed steels, available commercially, which are relatively insensitive to the phenomenon. However, such steels are more expensive than rimmed or semikilled varieties and are sometimes less attractive to the fabricator for other reasons. If susceptible steels are employed, the embrittling effects of strain aging after cold working may be removed by a heat treatment at or above the temperature at which recovery or recrystallization of the grain structure occurs. A temperature of 1100° F. (595° C.) for 1 hr. per inch of plate thickness appears to be satisfactory; lower temperatures for longer times may also suffice. Thus, a vessel thermally stress relieved after fabrication is relatively free of embrittlement unless subjected to additional cold working after such stress relief. Treatments prior to cold working are also helpful in reducing the severity of the embrittlement, although they are not capable of preventing the effect entirely.

Materials Division
Pressure Vessel Research Committee
Welding Research Council

INTRODUCTION

A pressure vessel made of steel, which our usual tests indicate to be tough and ductile, may fracture in a brittle manner if the vessel contains a severe notch. Factors which may contribute and augment the possibility of its occurrence are the sharpness and depth of the notch and the state of multiaxial stress associated with it, lowered temperature, and increased rate of loading (impact). Thus, a vessel, which at ordinary temperatures will perform satisfactorily in the presence of a certain notch, may fracture when some lower temperature is encountered. Cold work, as commonly used in fabricating operations, may under certain circumstances augment the tendency to brittle behavior. The factors contributing to brittle behavior may have a greater effect on some steels than on others.

* * * * * *

Plastic deformation occurs when the elastic limit of a metal or alloy is exceeded and is encountered in most fabricating and forming operations. When plastic deformation occurs at not more than slightly elevated temperatures, changes in the mechanical properties of the material are observed. For example, hardness and tensile strength are increased by plastic deformation,

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whereas ductility and impact toughness are generally decreased. The increase in hardness with plastic deformation has given this process of changing the mechanical properties the names *strain hardening* and *work hardening*.

Once a material has experienced a certain amount of plastic deformation, that is, once it has been *strained* or *work hardened*, no further changes in the mechanical properties might be expected until additional plastic deformation occurs. However, a few important materials tend to exhibit further changes in their mechanical properties after they have experienced a certain minimum amount of plastic deformation. This phenomenon is usually referred to as *strain aging* (that is, aging after straining). The term is applied to any change with time (i.e., aging) which occurs in the mechanical properties of a material after it has been worked at room, or slightly elevated, temperatures. The embrittlement that is associated with strain aging may be referred to as *strain-age embrittlement*.

The strain-aging characteristics of a rimming steel are shown in Fig. 1, where they are evidenced by a change in hardness values. Figure 1 shows another important aspect of strain aging. That is, the rates of aging increase with temperature. Thus, whereas at room temperatures maximum hardness was not obtained even after 10,000 min. of aging, at 400° F. (205° C.) only a few minutes were sufficient to cause considerable aging.

In addition to an increase in hardness, strain aging is generally also associated with an increase in tensile strength and a reduction in ductility and toughness. The reduction of the last two characteristics is indicative of the embrittling nature of strain aging.

Quench Aging

Strain aging should not be confused with quench aging. The latter term is used to describe the changes that may take place in a steel which has been quenched or cooled fairly rapidly from an elevated, but yet subcritical temperature.

Typical age-hardening (quench-aging) curves of a quenched rimming steel are shown in Fig. 2. Several differences between the strain-aging curves (Fig. 1) and the quench-aging curves (Fig. 2) should be noted.

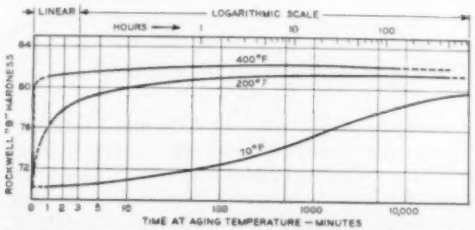

Fig. 1 Strain aging of steel; increases in hardness after cold rolling followed by aging at different temperatures (after Davenport and Bain[12])

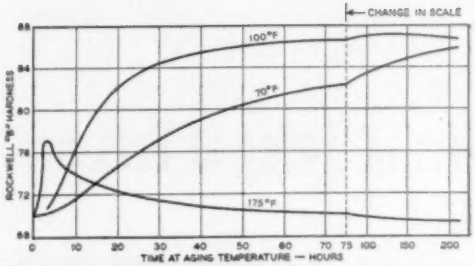

Fig. 2 Quench aging of 0.06% carbon steel; increase in hardness after quenching from 1325° F. and aging at the indicated temperatures (after Davenport and Bain[12])

For example, strain aging occurs much more rapidly than quench aging. On the other hand, after exposure for a few hours at temperatures above about 150° F. (65° C.), *overaging* generally occurs in quench-aged but not strain-aged specimens. The term overaging is generally used to describe a return to the properties which the material had before aging. The metallurgist associates overaging with the coalescense of small particles with attendant reduction in internal stress. At higher temperatures, overaging occurs more rapidly.

The same type of overaging does not occur during strain aging. This is apparent from Fig. 1, which shows that at temperatures as high as 400° F. (205° C.) a decrease in hardness from maximum values does not occur even after extremely long aging periods. Only at higher temperatures may a return to lower hardness values be noted (Fig. 10). Even at these temperatures the rates at which overaging occurs are much slower in strain-aged specimens than in quench-aged specimens.

Blue Brittleness

Since the tendency to strain age increases with increasing temperature, the rate may become sufficiently rapid to cause hardening and embrittlement during the actual process of plastic straining at elevated temperatures, Fig. 3. This generally occurs when steels, susceptible to strain aging, are worked at temperatures between approximately 300 and 1000° F. (150 and 540° C.).

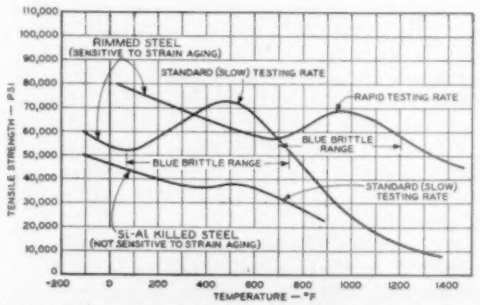

Fig. 3 Effects of testing rate and testing temperature on the tensile strength of rimmed and Si-Al killed steels (after Nadai and Manjoine[41] and others)

This temperature range, in which the strength increases and ductility and toughness decrease during working, is generally referred to as the "blue-brittle" range, owing to the blue oxide film which forms at these temperatures.

Mechanical properties at elevated temperatures of steels susceptible to strain aging may also be affected by blue brittleness. As is evident from the tensile-test data plotted in Fig. 3, the range of blue brittleness depends upon the rate of straining. Thus, the lower the rate of straining the lower will be the blue-brittle temperature range. The increases in tensile strength, shown in Fig. 3, are accompanied by reductions in ductility and toughness.

Steels which are not susceptible to strain aging are similarly not susceptible to blue brittleness. This is true of certain killed steels, as is indicated in Fig. 3.

It is important to note that the yield strengths of steels, susceptible to strain aging, which have not been previously deformed, do not increase with testing temperature. This is evident from the typical yield strength values for susceptible steels (not cold worked), which are shown in Fig. 4. The curves are representative of a minimum 60,000-psi. tensile strength steel. The elongation and reduction of area values, however, do indicate the effects of blue-brittleness by displaying minimum values in the neighborhood of 400° F. (205 °C.).

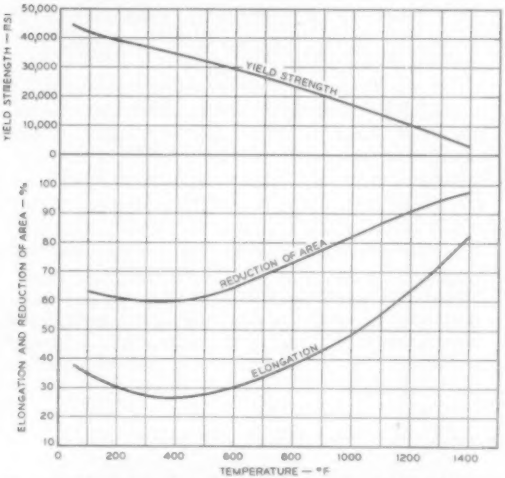

Fig. 4 Effect of testing temperature at standard (slow) rate of tensile testing on yield strength, elongation, and reduction of area of typical steels (after Miller and Heger[6] and others)

THEORY

From a theoretical viewpoint, strain aging is associated with precipitation type phenomena which appear to be primarily caused by nitrogen and, to a lesser extent, by carbon. The actual process is different from that encountered in a usual precipitation-hardening process such as quench aging. Phosphorus and oxygen are also believed by some investigators to aggravate the age-hardening effects of nitrogen and carbon. Generally, however, the action of phosphorus and oxygen is of minor importance.

EFFECT OF STEEL-MAKING PROCESS

Whereas some steels may be seriously embrittled by strain aging, other types are only affected to a minor degree. In a very general way, some of the major commercially available steels in the order of their susceptibility to strain-age embrittlement are listed in Table 1.

Typical compositions of the major types of mild steels which are used in pressure vessels are given in Table 2.

Considerable quantities of steel are made by the *duplex process*, which represents a combination of the acid Bessemer and basic open-hearth processes. This steel has a nitrogen content intermediate between that of Bessemer and open-hearth steels. With the normal fluctuation of the nitrogen content that is expected in

Table 1—Approximate Susceptibility to Strain Aging of Major Commercially Available Mild Steels (the Most Susceptible Steels Are Listed First)

	Steel	*Corresponding A.S.T.M. grades**
1.	Bessemer rimming steel†	A7
2.	Open-hearth rimming or semikilled steels	A7, A30,‡ A113, A131, A283, A285‡, §
3.	Open-hearth silicon-killed steels	A94, A201,** A212**
4.	Open-hearth silicon-aluminum killed steels††	A201**, A212**

* Additional A.S.T.M. pressure vessel or boiler steel grades which are alloyed with small quantities of Ni, Mn, Cr, Si, Mo, V and other elements are not listed in this table.

† Included for comparison only; Bessemer steels are not employed for pressure vessel applications.

‡ Boiler and firebox quality.

§ Flange quality.

** Pressure vessel quality.

†† The silicon-aluminum killed steels sometimes are also referred to as *fully killed steels*.

Table 2—Typical Compositions of Some of the Major Commercial Mild Steels

	Composition, %							*Main deoxidizer, lb. per ton of steel*
	*C**	*Mn*	*P*	*S*	*Si*	*Al*	*N*	
Duplex steel	0.08	0.38	0.019	0.028	0.007	...	0.008	None
Basic open-hearth rimming steel	0.07	0.45	0.006	0.020	0.005	...	0.004	None
Silicon-killed, open-hearth steel	0.27	0.52	0.016	0.025	0.22	0.006	0.006	7.7 lb. ferrosilicon
Silicon-aluminum-killed, open-hearth steel	0.16	0.51	0.013	0.020	0.16	0.035	0.005	7 lb. ferrosilicon, 2 lb. aluminum

* The carbon content is in part dependent upon the thickness of final rolling or shaping operations.

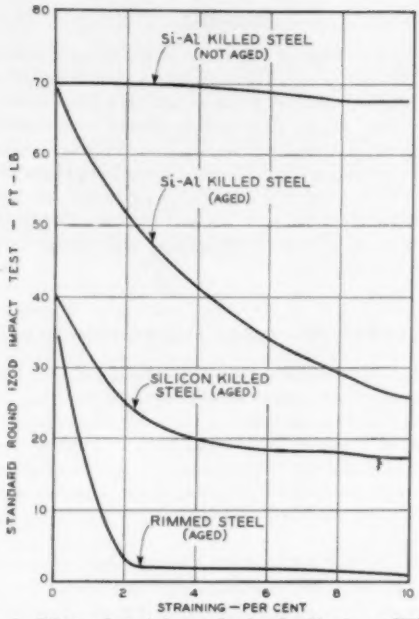

Fig. 5 Effects of straining and aging for 30 min. at 550° F. on the Izod impact toughness of various types of steels (after Wright[4])

the steel, the higher values will often run higher than the lower values found in Bessemer steel.

Characteristic curves which show the effects of the deoxidation practice on the strain-age sensitivity of several types of steels are shown in Fig. 5, where impact toughness is used as criterion. These curves, which represent extremely severe testing conditions, should only be used as a guide. They indicate that the rimmed steel is far more sensitive to strain aging than the silicon-killed or the silicon-aluminum-killed steel. Many exceptions exist and considerable variation in strain-aging characteristics can be found in the same grade. This is particularly true in the silicon-killed and semikilled steels. It is important to note that, in steels susceptible to strain aging, a decided decrease in notch toughness occurs as a result of straining alone (see, for example, Fig. 11), and, also, that even the silicon-aluminum-killed steels show a decrease after cold working and aging.

Impact tests, made at lower than room temperature, show that even silicon-aluminum-killed steels exhibit a marked decrease in impact resistance as a result of straining alone. Thus, notch-impact tests should preferably be made over a temperature range encompassing the transition from ductile-to-brittle behavior. An example of the usefulness of such tests is schematically shown in Fig. 6. As should be expected, the killed and rimmed steels exhibit different transition temperatures in the unstrained condition. Straining 10% and aging raises their transition temperatures. If, for the steels shown in this example, the tests are conducted only at room temperature the sharp change from brittle-to-ductile behavior might occur at perhaps 5% strain for the killed steel and at about 1% strain for the rimmed steel. Room-temperature tests alone would, therefore, not present a realistic picture.

It is generally desirable to use steels that are killed with aluminum and/or silicon since they are less susceptible to strain aging than the rimmed steels. However, for some fabricating operations such as deep drawing, rimmed steels may have certain advantages. Nevertheless, the major types of steel for pressure vessel applications are the killed and semikilled materials. Bessemer steels should never be used for such applications.

EFFECTS OF COMPOSITION

In rimmed and, to a lesser extent, in semikilled steels, nitrogen is the most important element which causes strain aging. In Bessemer steels, which are most susceptible to strain aging, the nitrogen content varies from 0.015 to 0.020%. In open-hearth rimming steels, the nitrogen content generally varies between 0.002 and 0.008%. Carbon also induces susceptibility to strain-age embrittlement which increases in proportion to the carbon content up to about 0.08% carbon. Above 0.08% carbon, additional increases will become less and less effective in further increasing susceptibility to strain aging.

The sensitivity of the silicon-aluminum-killed steels to straining and aging is believed to be related to the amount of aluminum nitride (AlN) in the steel. When most of the nitrogen in the steel is combined with aluminum to form aluminum nitrides (AlN), the steel seems to be *less* sensitive to straining and aging. When only a small amount of aluminum nitride has formed, even though ample aluminum is present, the steel will exhibit the usual sensitivity to straining and aging. The actual quantity of aluminum nitrides present seems to be determined by the heat treatment that the steel has received. Normalizing apparently favors the for-

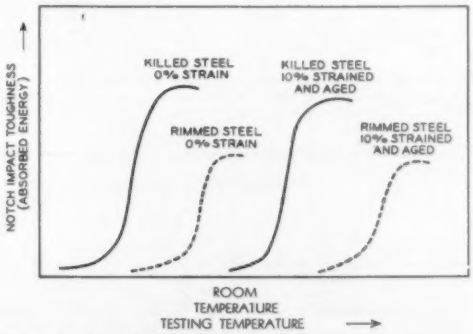
KILLED STEEL 0% STRAIN
KILLED STEEL 10% STRAINED AND AGED
RIMMED STEEL 0% STRAIN
RIMMED STEEL 10% STRAINED AND AGED
NOTCH IMPACT TOUGHNESS (ABSORBED ENERGY)
ROOM TEMPERATURE
TESTING TEMPERATURE

Fig. 6 Schematic sketch of effects of testing temperature on impact toughness of a killed and a rimmed steel

mation of aluminum nitrides and hence reduces sensitivity to straining and aging.

STRAIN-AGING CRITERIA

A number of different tests may be used either to determine the susceptibility of a particular steel to strain aging, or to simulate the behavior of susceptible steels during fabrication or in service environments.

The test specimens are generally strained 5, 10, or 15% at room temperature by pulling in a tension-testing machine or by cold rolling. Straining may also be attained by bending to a definite angle. Subsequent to straining, the specimens are aged at a suitable elevated temperature which serves to develop, in a short period of time, effects which might otherwise be produced only after very long periods at room temperature. An aging treatment of 1 hr. at 400 to 600° F. (205 to 315° C.) is quite commonly used.

Unfortunately, factors such as composition, heat treatment, cold deformation, etc., may affect some of the criteria differently. Moreover, the results which are obtained by these arbitrary laboratory tests may not always give an accurate prediction of the fabrication and service behavior of a particular steel.

The *hardness test* is the easiest method which can be used to predict the continuous aging characteristics of steels susceptible to strain aging. Unfortunately, the hardness test is relatively insensitive. Typical hardness curves of a rimmed steel, aged at different temperatures, are shown in Fig. 1.

In the *tension test*, the four major criteria, that is, tensile strength, yield strength, elongation, and reduction of area, are affected to varying degrees by strain aging. The tension testing may be done either at room temperature after aging or at elevated temperatures. In the latter case, the rates of strain aging during the test are sufficiently rapid to bring about changes in properties. This is associated with blue-brittleness.

Determination of the *tensile strength* is quite commonly used for revealing strain aging of steels in the blue-brittleness temperature range [ordinarily between 300 and 600° F. (150 and 315° C.)]. Typical curves showing the relationship between temperature and tensile strength are given in Fig. 3 for a rimmed and a killed steel. Comparison of tensile strength in the blue-brittle range with that at room temperature is one of the most effective ways of measuring strain aging.

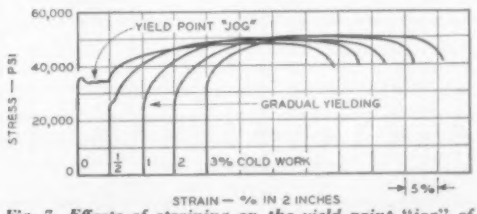

Fig. 7 Effects of straining on the yield point "jog" of annealed mild steel (after Griffis, Kenyon and Burns[9])

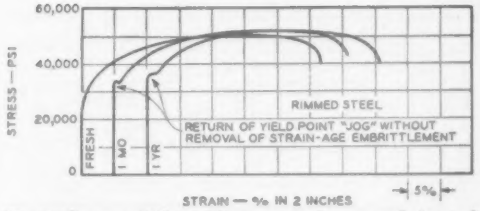

Fig. 8 Return of "jogged" stress-strain curve of rimmed steel during aging after straining by cold rolling by 1% (after Griffis, Kenyon and Burns[9, 11])

The *yield point* of mild and low-alloy steels disappears on cold deformation. This is evident from Fig. 7, in which are shown curves which are typical of rimmed as well as killed steels which have been previously cold worked by small amounts. After cold working the steel by about 1% and testing in tension, the yield point jog practically disappears. Moreover, gradual yielding occurs at a lower stress level. However, larger amounts of cold work again increase the stress at which yielding occurs and strain hardening becomes really apparent.

Aging of cold-worked steels susceptible to strain aging causes the return of the jogged type of stress-strain curves as well as an increase of the stress at which yielding occurs. Typical results are shown in Fig. 8 for a rimmed steel aged at room temperature. The increase in yield point is often used as a quantitative measure of susceptibility. It should be realized, however, that, although the yield point of a steel aged for one year is similar to that of a steel which has not been cold worked or strained (Fig. 7), the strain-aged steels are considerably more brittle, i.e., return of the jog in the stress-strain curve does not mean that the embrittlement has been removed. This strain-age embrittlement is not revealed by determinations of the yield point.

The yield point of a susceptible steel, which has not been initially strained, does not increase with an increase in testing temperature, as does the tensile strength as mentioned earlier, Fig. 4.

Steels, which are not susceptible to strain aging, will show no changes in the yielding characteristics as a result of strain aging. Typical values for a silicon-aluminum-killed steel which has been reduced by rolling by 1% prior to aging are shown in Fig. 9.

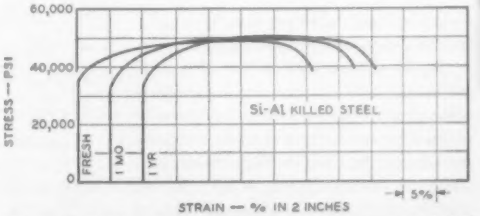

Fig. 9 Retention of rounded stress-strain curve of a killed (nonaging) steel during aging after straining (after Davenport and Bain[12])

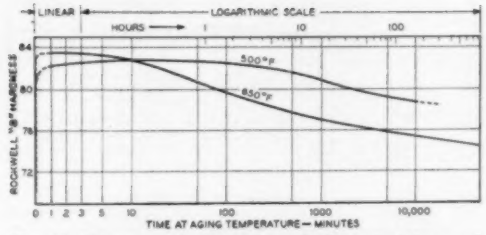

Fig. 10 Recovery of rimmed steel after straining and aging above 500° F. (after Davenport and Bain[15])

Steel preaged 17 hrs. at 212° F. (100° C.) Initial hardness of steel: R_B 70

Elongation is lowered by strain aging.

Reduction of area is usually lowered less by strain aging than the elongation.

Notch-impact toughness represents a particularly severe test of strain aging. Thus, notch-impact tests are most commonly used to determine the effect of strain aging upon the toughness of a steel. Typical results on several types of steels strained by various amounts and aged at 550° F. (290° C.) are shown in Fig. 5. However, as pointed out earlier, notch-impact tests should preferably be made over a temperature range which shows the transition from ductile-to-brittle behavior of the steel.

EFFECTS OF HEAT TREATMENT

When strain-aged steels are heated for sufficiently long periods at or above the temperatures at which recovery or recrystallization occurs, the distorted structure of the cold-worked steel is replaced by a new, strain-free grain structure. In this way, the effects produced by straining and aging can be eliminated. However, even by a treatment at temperatures somewhat below those at which recrystallization or complete recovery occurs, the effects of strain aging can be reduced. As is illustrated in Fig. 10, the minimum temperature at which overaging may occur is about 500° F. (260° C.). The degree of recovery increases and takes place more rapidly as the temperatures are increased.

Aging characteristics are also considerably affected by the heat treatment which the steel received prior to straining and aging which occurred prior to the fabricating operations. This is demonstrated in Fig. 11 in which are shown the effects of normalizing and furnace cooling [about 1° F. per minute from 1650° F. (900° C.) down to 1100° F. (595° C.)] on the strain-aging characteristics of a silicon-aluminum-killed, a silicon-killed, and a rimmed steel. The data in Fig. 11 show that furnace cooling results in a lower room-temperature impact toughness of silicon-killed and rimmed steels than is found in the normalized material. It is regrettable that the impact data were not obtained over the transition range. It should also be noted in Fig. 11 that, whereas the impact test showed considerable differences, the hardness test revealed little, if any, differentiation between the silicon-aluminum-killed and the silicon-killed steels.

The actual cooling rates depend to a large extent upon the thickness of the steel. Thus, normalizing seems to be sufficient even for rimmed steels up to a thickness of $^1/_2$ in. Thicker sections cool more slowly and, therefore, show a greater susceptibility to strain aging. They may have to be tempered in order to make strain aging less evident after straining and aging and testing at room temperature.

EFFECTS OF FABRICATION

The type of operation that is used in the fabrication of pressure vessels and structures may adversely influence the behavior of the steel and, therefore, the choice of the steel and the necessity for heat treatment.

Steel plates are generally manufactured in a grade of

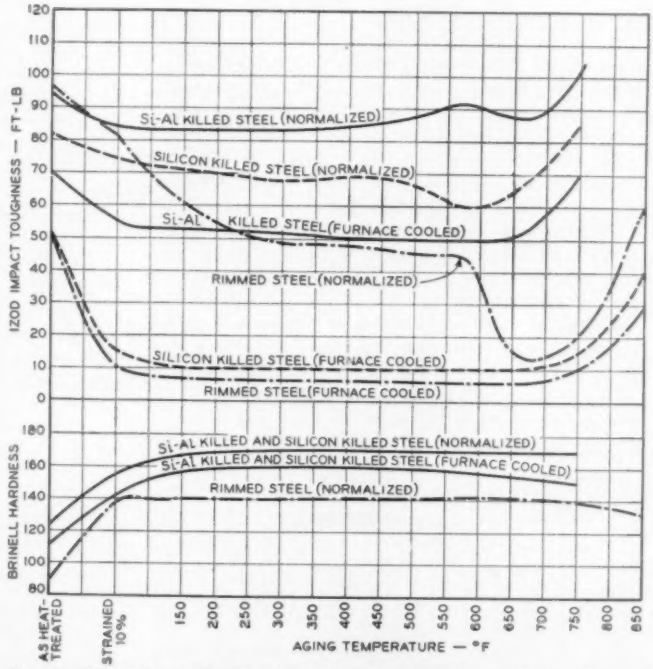

Fig. 11 Effects of prior heat treatments on the aging characteristics of several steels which have been strained by 10% and aged for 30 min. at various temperatures (after Enlund[15])

flatness known as commercial flatness, which is produced in the steel mill, by a roller leveling. In this operation, straining rarely amounts to over 1%.

Steels, which are susceptible to strain aging, may be seriously embrittled by galvanizing if they have been previously subjected to cold deformation. Thus, if punching, shearing, and similar operations have included strain aging and notches, brittle failures in the deformed area may occur after galvanizing.

If straining of steel plates susceptible to strain aging has been severe enough to affect the forming characteristics detrimentally, a normalizing or tempering heat treatment may be advisable prior to the forming operation.

Effects of Drawing and Forming

If heavy forming operations are to be made on rimming steels, the extent of and the susceptibility to strain aging of the particular steel should be known. If the steel has been embrittled, heat treatments prior to forming may be necessary.

When multiple drawing and forming operations are to be made, no long periods of time should be allowed to elapse between operations. This is particularly true of forming operations that are made at the moderately elevated temperature at which strain aging occurs more rapidly than it does at room temperature. Excessive strain aging may be responsible for a sufficient reduction in drawability to cause failure. Steels preferably should not be formed above 350° F. (175° C.) because, above this temperature (in the blue-brittle range), the rates of strain aging are quite rapid and may cause rupture during the forming operation.

However, it is important to realize that, although strain aging may be responsible for failure in drawing operations, other factors may also be involved. Thus, the manner of the drawing operation, the design of the drawing dies, and lubrication are generally at least as important as the mechanical properties of the steel.

In cold-worked sections, the effects of strain aging may be minimized by a tempering (softening) treatment between 1100 and 1200° F. (595 and 650° C.). Higher temperatures are often undesirable because of the susceptibility of the strained steel to grain growth.

Effects of Shearing, Punching, and Stamping

Shearing, punching, and stamping of rolled plates of grades susceptible to strain aging may cause severe embrittlement. The embrittlement is particularly severe when these operations are carried out at 400 to 750° F. (205 to 400° C.) as may occur in steel-mill practice where plates are sheared while still retaining some of their original rolling heat. The effects of strain aging are most economically removed by heating the strained section to dull redness with an oxyacetylene flame, or the sheared edges may be planed or machined.

Rivet holes are frequently drilled rather than punched or reamed after punching in steel over $^1/_2$ in. thick. Punching of steel $^1/_2$ in. or less in thickness usually does not cause any harmful embrittlement.

EFFECTS OF WELDING

Very little useful information is available on the effects of welding on strain aging.

Ordinarily, strain aging of welded sections does not seem to be sufficiently severe to merit concern in most industrial installations. Most difficulties arise when straining is followed by welding, especially in a region where there is a sharp notch. Special considerations may also have to be made when some cold deformation occurs in a welded section of a steel which is susceptible to strain aging. For example, special attachments and fixtures are often welded to certain vessels or structures. The small amounts of subsequent strain, introduced when certain parts are lined up, may snap the fixture.

If welded sections are suspected of having become embrittled, local heating with a torch to temperatures above 1100° F. (595° C.) may be advisable to cause removal of the strain-age embrittlement in the strained section. Because of the difficulties in the temperature control by local heating with a torch, particularly when local overheating produces undesirable metallurgical changes in the steel, it is preferred practice to employ stress-relieving (tempering) furnace heat treatments at 1100° F. (595° C.). In fact, such a stress-relieving (tempering) furnace heat treatment is specified in paragraph UW-40, Rules for Construction of Unfired Pressure Vessels, Section VIII, A.S.M.E. Boiler Construction Code, 1950 Edition. The temperature should not be less than 1100° F. (595° C.)—a maximum of 1150° F. (620° C.) being suggested.

Deformation of the weld metal, which may be caused by differential cooling and shrinkage of restrained sections, generally will not amount to more than 0.15% elongation and, as such, will not significantly cause strain aging. However, in cases of extreme restraint, straining may amount to as much as 2%.

Bending of welded as well as unwelded sections, even at slight angles may introduce considerable strain. For example, a bending angle of 1° causes about 5% elongation at the base of a U-shaped notch (0.020 in. deep, $^1/_{16}$ in. radius) in a $^3/_4$-in. plate.

Prevention of Strain Aging

Strain aging may be minimized most effectively by the use of silicon-aluminum-killed open-hearth steels. Grades which are susceptible to strain aging, such as the rimmed steels, may require special heat treatments above 1100° F. (595° C.) before and/or after the fabricating treatment. To a considerable extent this depends upon the amount of straining and the temperatures at which fabrication procedures are performed, as well as on the service requirements which the steel has to meet.

FIELDS FOR FURTHER STUDY

A careful reader of the foregoing review will realize that there are many gaps in our technical knowledge of strain-aging embrittlement. For instance, the matter of heat treatment has not been completely explored. From the practical standpoint, it would be useful for the fabricator to know without question whether a given type of steel should be in the as-rolled, normalized, or annealed condition prior to straining, to minimize the embrittlement following forming operations. Also, more complete knowledge regarding suitable post-treatments to remove the effects of strain aging would be useful.

A subject which is practically unexplored is the relationship between welding and strain aging. Except by inference, there is very little technical knowledge concerning whether strain aging is a significant factor in structures joined by welding.

Likewise, the effect of small amounts of the alloying elements commonly used in low-alloy steels has not been fully explored.

Finally it should also be recognized that, except in marginal pressure vessel applications, the degree of brittleness which can be tolerated without affecting serviceability is not too well understood and is, in fact, a controversial topic. It is unlikely that brittleness resulting from strain aging is any different, from the service standpoint, than brittleness arising from any other source. The importance of freedom from brittleness as a factor in serviceability may be generally recognized, but only in a qualitative rather than a quantitative sense.

All of these subjects can form points of departure for fruitful research of both theoretical and practical nature, designed to assist the producers and users of pressure vessels in solving their mutual problems to the benefit of industry as a whole.

ACKNOWLEDGMENT

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Since the above discussion is to serve primarily as an interpretive engineering statement of the present knowledge of strain aging, detailed research results as well as theoretical hypotheses have been omitted. This and other information can be found in articles listed in the Bibliography. General discussions of strain aging are found in references 1, 9, 11, 12, 14, 24, 27, 30; blue-brittleness in 36, 38, 42; effects of welding in 6, 20, 21, 33, 39, 42, 45; of heat treatments in 13, steel-making practice 8, 10, 15, 16, 19, 23, 34; composition in 2, 7, 9, 22, 29, 32; tests in 35; fabrication in 17, 18; precipitation or knot theories of aging 2, 3, 4, 5, 30; and stress corrosion cracking in 25.

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Interpretive Report, Fabrication Division, Pressure Vessel Research Committee

Discussion by Members of P.V.R.C.

On Sept. 8, 1950, the P.V.R.C. Central Office called the attention of the entire Committee membership to H. C. Boardman's interpretive report on the work of the Fabrication Division, P.V.R.C., from 1946 to 1950. Each member was urged to study the report in detail, to draw further conclusions, suggest new hypotheses and to make any other comments that might render the report more useful to those in the pressure-vessel industry.

As a result, a number of comments have been submitted to date. These indicate, very definitely, that it is the unanimous opinion of those replying that Mr. Boardman's report constitutes a very valuable and outstanding service to the engineering profession, and that the author has performed, most skillfully, a very difficult task in providing and presenting a very comprehensive interpretation of the Fabrication Division findings in familiar engineering terms.

The highlights of the other specific points of discussion are given below.

Comments by Henry Liessenberg

Mr. Liessenberg, of Combustion Engineering-Superheater, Inc., has pointed out that Mr. Boardman's report, covering four years of actual tests conducted under the sponsorship of the Fabrication Division, contains much information never fully realized before, and thus should be of great interest to every manufacturer in this field. He has stated, in part, as follows:

"The tests conducted at Lehigh University on two different steels of two different thicknesses have opened the eyes of every interested engineer as to effect of cold work, welding, low-temperature stress-relieving, annealing at 1150° F. and normalizing at 1600° F. These tests of course scratched only the surface, and more tests for different steels at variable temperatures and effective time per inch of thickness for stress-relieving will be required to obtain sufficient data for the better grades of steels to determine safe economical operating range. The end result will be more rigid specification for certain operating conditions to guarantee safe design.

"Under material tested at Lehigh University, (*a*), the chemical variations at different points in the ingot were consistent with the physical variations of strength and ductility. This may lead to even larger ingots, so that a larger mass of identical properties could be obtained, and each section of the ingot would be within certain specifications for limited operating conditions.

"Under (*c*), it is pointed out that normalized material has a greater ductility than as-rolled plates; in (*e*) also, that thinner plates have a higher yield point and greater strength than thick plates due to larger amount of rolling. Why is this fact not given credit in certain parts of construction as layer vessels, where only thin plates are used for layers?

"Of outstanding interest is the paragraph on 'Effect of Plastic Strains and Heat-treatment,' where Mr. Boardman points out that normalizing at 1600° F. was the only heat-treatment which consistently restored ductility and transition temperature of the cold-worked plate to the original values. Heat treatment at 1150° F. gives this advantage only partly and not always. Of course, 1600° F. is impractical for large welded vessels due to expensive structure to prevent deformation of the shape. It will be of great interest to find out in the mentioned future program the effect of lower temperature heat treatment and time required per inch of thickness to obtain almost identical results. Such tests of course involve tremendous time and study, as well as money, and it is hoped that a test-minded industry will visualize the serious need of such investigation and will support such an undertaking financially so that final Rules and Regulations can be written for all steels."

Comments by H. O. Hill

Mr. Hill, of the Bethlehem Steel Co., has questioned that the experimental data presented to date warrants the conclusion drawn in the following paragraph:

"*Caution:* Some of the results reported by the Subcommittee on Cold-Formed Heads indicate that a yield point obtained by cold working may, after aging, drop back appreciably toward its original value. Therefore, designs based on yield points obtained by cold working should be used only when the permanency of the raised yield points has been established."

Mr. Hill has recommended that the following wording be substituted for the above:

"*Caution:* Some of the results reported by the Subcommittee on Cold-Formed Heads indicate that a yield point obtained by cold working may, after aging, increase for a period and then drop toward the value obtained by the cold working. Subsequent testing over a period of time, will be necessary in order to determine if the higher yield strength obtained by the cold working is dissipated. In the welding zones, of course, the heat due to welding will destroy all gain in yield strength obtained by the cold working. Therefore, designs based on yield points obtained by cold working should be used only when the permanency of the raised yield points has been established."

Paper by H. C. Boardman was published in the Research Supplement to the September 1950 issue of The Welding Journal.

Comments by W. Spraragen

Mr. Spraragen was an active member of the original Subcommittee that assisted Mr. Boardman in the preparation of the Interpretive Report. In addition, he has contributed the following thought-provoking and constructive discussion on the published paper:

"The interpretive report of the Fabrication Division should be a 'must reading' by every engineer concerned with the cold working and fabrication of metal structures. It is easily worth the entire cost of the Pressure Vessel Research Program.

"Unfortunately, a research report accomplishes little until something is done about it. First of all there is an area of application where no action seems to be indicated as yet. I refer to shop structures where the metal operates at substantially room temperatures. There is another area where the results obtained may not be significant. This is the region of elevated temperatures. Steels which will give the very best performance for low winter temperatures may not be the best for elevated temperatures.

"When it comes to structures subjected to low winter temperatures the results indicate that rules, regulations, specifications and procedures should be tightened up.

"Let us start with the designer first. He must examine his points of stress concentration with double care if his structure is to be operated at winter temperatures. At such points he may be providing the wherewithall to start a crack if he does not take in account that his strained material at low temperature is much more notch sensitive.

"Code and regulating bodies and fabricators must with our present state of knowledge require additional tests of materials for structures to be operated at low winter temperatures. A test such as the Lehigh or Kinzel test is definitely indicated if we want the insurance of a safer structure. These tests, properly performed at the lowest temperature at which the structure will operate, will eliminate undesirable heats which become more notch sensitive after straining and welding. They automatically provide straining and at the same time can provide assessment of the heat effect of welding. True enough that these effects can be lessened by preheating and thermal treatment after welding. However, these same treatments can be used on the specimens before rejecting any particular heat of steel.

"The fabricator knows that he must resort to preheat or postheat, or both, unless he assures himself he has steel that will not become notch sensitive in the heat-affected zone where a crack may start through no fault whatsoever of the designer. The steelmaker must look to further research to tell him why two heats of steel made to the same specifications are affected so differently by the heat of the welding cycle. Surely he can expect the designer to produce a structure which will not initiate a crack at a stress concentrator but he, in turn, must produce a steel which is not notch-sensitive at winter temperatures under normal fabricating procedures. A steel which permits a crack to start in the heat-affected zone after standard welding procedures are used, with good design and workmanship, must be eliminated.

"There is one additional point suggested to Mr. Boardman which was not included in the interpretive report, namely, that some research indicates that slow cooling after welding from 500° F. to room temperature or perhaps the use of low hydrogen electrodes seems to be desirable. Code rules may have to be tightened in this respect."

Comments by Frank W. Davis

Mr. Davis has indicated his particular interest in the information pertaining to the relationship between reduction in cross-sectional area, as obtained from room-temperature tensile tests, and transition temperature as determined by both Charpy Tests and Lehigh Slow-Notch-Bend Tests.

"Charpy tests at low temperatures are costly," Mr. Davis has pointed out. "Difficulty has been experienced in obtaining consistent results by a number of industrial laboratories. If a correlation between transition temperatures and reduction of area of tensile specimens could be established, the selection of ferrous materials for low-temperature service would be greatly simplified."

At the same time, Mr. Davis has been somewhat critical of the following statement by Mr. Boardman in the first paragraph of the "Summary":

"Actually all cold forming operations raise the yield point closer to the ultimate strength; welding generally reduces the toughness of the heat-affected metal and always locks up a lot of stress in the joints; and even the most ductile material, according to the measurements at room temperatures, fails brittlely under conditions of low temperature or restraint preventing plastic flow."

Mr. Davis believes that the statement relative to the brittle failure at low temperature should be limited to ferrous materials, bringing out that it is a well-known fact that the nonferrous materials do not become embrittled at subzero temperatures.

Comments by Walter Samans

Mr. Samans, past Chairman of the Pressure Vessel Research Committee and one of the original contributors to the Boardman report, has expressed the following views:

"This report, considered to be a summary to date of the work done by the Fabrication Division under the able leadership of Mr. H. C. Boardman who also prepared it as an interpretative review of new findings or confirmation of older assumptions, is not by any means to be taken as satisfying the program planned for this phase of the activities of the Pressure Vessel Research Committee. It was not published with that

intent, and a careful comparison of it with the problems facing the engineers responsible for pressure vessels will show that much further work needs to be done.

"This generalization should in no way detract from equally potent reasons which may be advanced in the need for more information on rules for design of critical details for completed vessels of special alloys, and the larger field-assembled vessels that truly belong under the scope of a pressure vessel code, and on methods of testing these vessels.

"It seems only natural that most engineers concerned with fabrication of pressure vessels should look at the problem objectively, namely, keep production rate up and costs down. This will usually serve only for vessels within shop-built sizes, of moderate dimensions, thickness, and simple service requirements. The Fabrication Division had much more than this in mind, because of the increasing need in industry for pressure processing, to make use of vessels of unusual shape and size with complex details, and high alloys of steel requiring special heat-treating procedures.

"For many years, the engineer has heard about ductility or toughness, brittle fractures, impurities, surface defects of various kinds, and had some conception of their meaning and relative importance. More recently he reads about notch toughness, strain aging, cohesive strength fracture with significance placed on energy before and after a cleavage failure, the range of transition temperature, 'good or no good' ductility as determined by impact tests or slow-notch-bend tests in various types of specimens. All of these later terms appeared to have only a somewhat distant relationship to three-dimensional practice in pressure-vessel construction. It first seemed to him that a more burdensome mill and shop inspection procedure might be the outcome, thus only increasing his difficulties.

"The findings given in Mr. Boardman's report should serve to allay his misgivings, in that prestrain in fabrication may not be so injurious to the finished vessels as in prepared specimens having artificially imposed defects. Fortunately for the engineer's doubts, men selected by the contributing interests to be on the Pressure Vessel Research Committee have not lost sight of the practical objectives, after the early realization that much time would initially be needed to review past performance, to look for all useful records that might be made available, and to get the fundamental facts.

"Much more needs yet to be done in evaluating what the shop hydrostatic tests can accomplish. To show leaks in welds and around ineffective closures has been its primary purpose so far, and now that the tests on considerable cold prestraining have shown the degrees of permanent harm possible, the hydrostatic test may serve to equalize the peak stresses around welded seams and around most critical details if proper thought is given to the method of assembly and resultant shape with reference to stress raisers. As far as our present knowledge goes, it will not take precedence over thermal stress relief.

"The author points out that the engineer has the confirmation that normalizing carbon steels at 1600° F. is the only heat treatment which surely restores the original ductility to cold-worked steel, but need we necessarily be disappointed that 1150° F. is not equally effective? This temperature is the minimum specified for stress relief of welded joints in carbon steels, and has well served its purpose. Possibly its effect is more noticeable on the base metal in the heat-affected zone when a rimmed steel is used, and thereby justifying the use of this steel, with a few proper limitations as to service requirements. That could stand a more thorough study.

"The writer is not wholly in sympathy with the apparent belief of the author that the pressure vessel engineer 'longs for tougher steels than are now available at prices which he can afford' to recommend. Nor is he really concerned about maximum combined stresses with relation to code allowable direct stresses, unless they are so distributed that resulting deformation in a vessel wall will further accentuate the overstress.

"While it must be conceded that exact reasons cannot be adduced for the marked difference in mechanical behavior of different heats of steel intended to be alike, that is, made to the same specification, the writer does not think engineers need be unduly alarmed by it. The customary degrading of the product from a heat which is too far off specification is considered acceptable. When one considers that serious failures in shop tests of vessels are rare, and that many of the destructive failures in vessel operation have been pinned to thoughtless or out-of-control mis-operation, we should by reason of the present findings approach the future with greater confidence, provided proper engineering check is had on design, inspection and the selection of material and its fabrication. We will simply have to assure ourselves that no primary material defects are placed or left in critical locations.

"The concern for the successful lifetime operation of a pressure vessel should not so much depend on the factor between the minimum tensile strength of a standard specimen, and a maximum direct stress value given in a code table, or its nominal ductility expressed by a selected method of test serving for comparative estimation of toughness, as on the deficiences that are in the finished product—in this case the completed vessel—at places where actual strain may propagate any such deficiency into an irreparable failure.

"We cannnot all have the best of everything, even if we could afford it, and the engineer's preference should incline toward making the best he can of what can be made available under reasonable expectations. The author has recognized this in the very practical conclusion 'that for an unpredictable time, the safety of plain carbon steels will depend more upon careful design, fabrication, inspection and testing than upon improved steel quality,' and that the work of the Fabrication Division has been most helpful in bringing to the Engineer a realization of this condition.

"The writer believes that most engineers have been fully aware that this is so, and, except in special cases, are prepared to use all qualities of steel to best advantage. Their principal aim should be to freely recommend the use of the higher quality steels where the conditions of service demand its use, and to try to assure that none of the steels available are misused, even those of the lowest quality.

"It would be an oversight, if the writer failed here to compliment the author and the members of the Fabrication Division on their efforts to carry on the major beginnings of a program of research that will be growing with increasing demands by industry for bigger and better vessels.

"If it is failures of pressure vessels that are presumed to be the criterion for the need of more research work, consider the following experiences:

"The occasional failure of pressure vessels under a shop hydrostatic test and those more numerous in scheduled service tests during shut-downs in process plants do not get much publicity. Certainly, operational service failures are seldom reported unless a large incidental loss makes it a news item. Sometimes those brought to the attention of the P.V.R.C., when not the result of mis-operation, have been due to low quality of base material, but more often they were due to a perfunctory design or fabrication procedure and in its broader sense including inspection. Basically these failures are not due to lack of code formulas for design, but might be so classed if it is concluded that the detailed control of shop practices should be codified.

"Because of conflicting reports from many sources, the pressure vessel engineer, whether the vessels individually cost $100 or $1,000,000, feels that he should be informed how results on tests of laboratory specimens are to be correlated to a commercial pressure vessel, of which hundreds of thousands have served their purpose, but on which some technicians are now casting doubt as to their lasting safety.

"Obviously, with the larger and more important structures now within the pressure vessel field, the engineers responsible for their successful service, anywhere along the line from material manufacture to the vessels' operation and maintenance are entitled to the financial backing and constructive criticisms which the users and manufacturers and fabricators can contribute.

"Basic data must always come first, and progress made after that should be really gratifying to all concerned from now on. If this need for research on pressure vessels was urgent five years ago, it now is even more so."

Comments by F. V. Hartman

Mr. Hartman, Aluminum Ore Co., has commented as follows:

"Mr. H. C. Boardman's report is an excellent review of the work done to date by P.V.R.C. He asks a lot of pertinent questions concerning the various laboratory tests and what they mean in terms of a fabricated vessel. It seems his biggest contribution to the average engineer is to make him more conscious of the many variables in pressure vessel design and fabrication—which as yet are not fully understood and have not been explained by laboratory tests. Such a timely review or evaluation of results asking what has been accomplished and the general direction for future efforts should be a big help in planning the continuation of this program.

"I am a bit puzzled, however, over the report and especially the title. It leaves me in the dark in regard to what has been accomplished by P.V.R.C. I'm not sure whether this is a criticism of the paper or of P.V.R.C. I'm inclined to think, however, that the implication is that the P.V.R.C. activities should be reviewed carefully."

Comments by H. B. Oatley

Mr. Oatley, of Combustion Engineering-Superheater, Inc., has emphasized in his comments that the interpretative statement prepared by Mr. Boardman and his cooperators should be of great value not only to the Engineer who must make direct use of such information, but to the Executive as well.

Comments by George W. Watts

The discussion submitted by Mr. Watts, of Standard Oil Co. (Indiana), is indeed, very stimulating and constructive. Mr. Watts has this to say:

"By summarizing the work which has been sponsored by the Fabrication Division, P.V.R.C., and stating its practical significance as applied to pressure-vessel problems, Mr. Boardman has rendered a real service to industry. Seldom has such a difficult task been done so well.

"In particular, his presentation of the Lehigh investigators' concepts of 'ductility transition temperature' and 'fracture transition temperature,' together with some thoughts on the relative importance of the two transition temperatures, is exceptionally clear and concise. Even though the exact significance of these transition temperatures, with relation to actual structures, is still somewhat obscure it is obvious that they furnish a useful measuring stick for evaluating the effects of other variables.

"Although the reported relationship between reduction in area, in a room temperature tensile test, and the notch-brittle transition temperature is interesting, it is difficult to see how it can be truly significant or very useful, particularly in view of the scatter found in the data. It seems unlikely also, that the simple linear relationship suggested could be valid. However, with the existing scatter, numerous other relationships, e.g., log reduction in area vs. reciprocal absolute temperature for the transition, would fit the data equally well and might have a much more fundamental meaning.

"It certainly is not comforting to know that steels which might have relatively low impact strengths can be used at present for atmospheric temperature service

(down to −20° F.) in compliance with the A.S.M.E. code. However, if any test is to be selected to determine the suitability of a steel for this type of service, would it not be better to require a minimum energy absorption in an impact test at the lowest expected service temperature, whether this be a process or an atmospheric temperature, than to require a minimum reduction in area in a tensile test at a temperature (so-called room temperature) which might be well above this operating temperature?

"Admittedly there might be a great deal of opposition to such a suggestion, but should this invalidate it? The mere fact that our failures thus far have been scattered and not publicized scarcely warrants the conviction that we will not have much more trouble in the future. We may have been very fortunate up to now, but even one serious failure could change that picture overnight. It might be pointed out in this respect, that each interested group has its own problems which should be concentrated on rather than trying to solve the problems of the other groups. The Engineer must concentrate largely on removing possible notches from designs; the Fabricator must do likewise with construction; Management must either become resigned to somewhat higher material costs if a real diminution in the possibility of failure can be achieved thereby, or else find some way of offsetting these higher costs; and the Metallurgist and Steelmaker must learn how to control the notch-brittle transition characteristics and to make steels, which will be reliably ductile, for these atmospheric and subatmospheric applications. Each group has its own problems to solve. The other groups can apply pressure and cooperation in understanding the problems but they cannot solve, themselves, the problems of the others. Certainly no steelmaker will accept any requirement in a specification when he has no real idea of how to meet it.

"The real problem for research today would seem to be to find out how to make carbon steels for low atmospheric temperature service at a reasonable cost, but it probably is a subject which is receiving little attention. Almost of equal value, however, if it could be found, would be a nondestructive means of determining the notch-brittle transition range. If such a method were available, tests could be made on pressure vessels, after erection, and some significance might be attached to the phrase 'the transition temperature of a vessel' which now is somewhat meaningless, as Mr. Boardman points out.

"It is interesting to find, also, speculation on the true reasons for the benefits arising from preheating and postheating treatments. To all appearances the major effects are metallurgical rather than in the relief of stress. If this is confirmed, it might be wise to examine these treatments more critically as to their real necessity for some types of applications. If post heating must be done in this field the cost may be very large so it is important to determine if its effects are really worth the price we pay for it.

"The work of the Fabrication Division thus far seems to have provided answers to many controversial questions and to have supplied considerable general information of a fundamental engineering nature. However, we agree with Mr. Boardman that basic understanding still is missing in most instances. Whether or not the complete solution ever will be found cannot be stated. The P.V.R.C., at least, has had the courage to admit that there is a real problem existing and to make a serious attempt to attack it and find a solution."

Discussion by Wendell P. Roop

The idea of a transition temperature for a complete vessel, says the author, is illusory. No laboratory test can be found to correlate directly with service vessels. If these words are to be taken at their face value, then the best we can hope for is better luck.

Everyone agrees that diminished risks are the best we've got so far; at worst we have no assurance even that risks have not increased.

But no one is willing to let the matter rest there. It is my own opinion that we can hope for something better. The way to get it is to aim at bringing conditions of test closer to those of service. Until that can be done, we still will depend, for learning how to prevent casualties, on breaking a service structure every time the conditions of its design, material or construction are radically changed. Since few are willing to break full-scale structures in test, we are, in effect, then only waiting for another to break in service.

The reason why earlier hopes for a direct correlation between test and service were disappointed is not just that materials are too variable; we know that they are variable and we know what to do about it. It is not just that in the extended vessel a great variety of elements and situations exist; we have always known that and have dealt successfully with the fact. It is not even that it costs too much to make good steel. It is something easier to understand than any of these, namely, that we still don't know how to recognize good steel when we have it.

The only good steel is steel that will make a good structure, and our job is not finished until we have a laboratory test that will tell us whether steel, like a given sample, will make a good structure. The one reason why we still don't have such a test is because cold brittleness of steel is affected by geometry, including absolute size.

Now we are invited to believe that a Charpy specimen $^1/_2$ in. square contains more truth than a ton-size plate. It is not impossible that this is correct; but, if so, we will prove it by understanding what happens on the way to fracture in both pieces of metal. No amount of blind plotting of this or that against that or this will ever take the place of such proof. I have not

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Wendell P. Roop, Swarthmore College, Swarthmore, Pa.

yet seen a correlation chart between date of rolling and phases of the moon, but no doubt that too has been tried.

For the future there is no need of pessimism. Only within the last year or so have we become aware of the importance of something we knew all the time, namely, that fracture occurs in two stages.

In the old days, when elastic behavior still seemed important, we regarded the first breach of continuity in the metal as the threshold of ruin. A crack is a more acute notch than any that can be made by a cutting tool, isn't it? And does not every notch act as a stress-raiser? And is not the concentration at the apex of a notch greater as the notch is more acute? And when the notch radius is zero, how can the stress, even under moderate load, be less than infinite? And when a material with a paltry 60 ksi. of tensile strength encounters infinite stress, how can it do anything but break?

But now it seems not so, not so. Yes, it is true that in a machined notch a natural crack will appear at an early stage of loading, perhaps earlier as the notch is sharper. But in the gross behavior of the loaded metal that makes very little difference; if the metal is ductile it goes right on flowing as if the crack were not there. Only by looking sharp can we even see the crack. Many specimens are of such a form or are loaded in such a way that it can't be seen at all.

Since however the crack is always there when not hidden, I believe that it is also there when it is hidden. Even in an ordinary round tensile test piece it is known that at some stage a crack opens up on the axis. It does not cause immediate total rupture; it is quite possible that the crack is there at the start of necking.

Even when final rupture is brittle, it is preceded by plastic flow and by a preliminary crack. What is it that defers the final rupture? We do not know, but we may suppose that it is somehow connected with the extent of strain hardening in the zone of intense strain from which the incipient fracture will presently take off.

When that take-off occurs, the whole aspect of things is changed. If it does so in the brittle mode it goes very fast and can't be stopped. If it is ductile, the speed of advance of the fracture is limited by the rate at which the halves can be separated. Under dead weight load, it can still go pretty fast, but in a testing machine elongation relieves load and the process can be prolonged or stopped *ad libitum*.

Now these two stages of fracture are combined in different ways in specimens of different form. It is a question of the extent of metal involved. The preliminary stage will naturally affect mainly the metal near the starting point at the apex of the notch. In a large specimen this will be only a small part of the whole specimen, but as the specimen is smaller a greater part of it will be involved in the preliminary phase of the action.

In very small specimens the particular shape of the zone of preliminary action will also be important. Thus in a small specimen like a Charpy bar this zone will extend further around a keyhole notch than around a V-notch. It may be large enough to extend all the way across the section, especially in a tensile specimen like that of Schnadt. Load in bending will reduce the size of the zone.

The difference between the Charpy bar and the Lehigh plate is mainly one of width in the dimension parallel to the notch. We have gotten into the habit of describing the effect of width as one of "restraint," and no doubt the stress system in the elastic range is affected by width. But a more important effect is that on the extent of plastic flow in the preliminary phase of fracture.

Near the edges of a Lehigh plate, flow follows a pattern different from that at mid-width, where strain in width is not as free as that in thickness. But the compression crowds the zone of preliminary action toward the notch at both places. This zone is always centered near the surface of the plate, where the properties of the steel may be quite different from those at mid-thickness.

The Navy tear test, like the two already mentioned, is also eccentric; but the specimen is larger, the notch extends across the full thickness of the plate as-rolled, and the crack advances as it does in service, parallel to the surface. The preliminary stage of fracture can be directly observed, and it is seen to end nearly at the stage at which the load reaches its maximum value.

It might be supposed that in the Navy tear test load would be forced to fall off as soon as any encroachment on net area occurred, especially as the notch lies at the point of most intense tension. It is exactly the point of significance about the preliminary stage of fracture that this does not occur; the load goes on rising long after the crack has opened up. It is a later event that causes the load curve to turn downward, namely, the beginning of more rapid and definite advance which *ends* the preliminary stage.

The extent of metal in the preliminary zone is a smaller part of the whole in the Navy tear test than in the bend tests. But since it is the energy absorbed *after* maximum load that is chosen as the index of ductility, what happens in the preliminary stage is largely ignored.

The internally notched wide plate is like two tear specimens joined at the notched edges. It is the only specimen here considered which permits wide variation of the relative extent of the zone of preliminary fracture. I will therefore add some information drawn from this specimen to that summarized by the author.

This information relates to the transition temperature. The author refers to two transitions: T_B (B for bust) and T_N (N for not-bust). Instead of this, the wide plates tell us only about two stages of fracture, the preliminary stage, confined mostly to zone E (E for Elongation), and the final stage following zone D (D for total Destruction). In the most complete analysis I have also identified zones A, B and C, but these will be left aside for now since they refer to incidental energy not directly associated with fracture.

It is very tempting at once to associate T_N with zone E and T_B with zone D. However, the data on this are not yet conclusive or perhaps even the data already published have not been sufficiently studied in a rigorously critical spirit.

In the wide plates, variation with width on plate both of the energy in the ductile condition and of the transition temperature is getting close attention. It is not too soon to say that these variations are quite different in nature according as the energy value considered is that absorbed before or after maximum load.

Plotting energy before maximum load reveals rather vaguely a pattern which may be described as follows:

(*a*) The average density of fully ductile energy to maximum load diminishes as width increases.

(*b*) As temperature goes below a certain limit, this energy may fail to reach its fully ductile value. This limit is the same at all widths.

(*c*) As width is less, the reduced value of energy below the limit rises toward the fully ductile value. In specimens not over 8 thicknesses wide the two agree and the transition disappears, as in the tear test.

When energy after maximum load is plotted the pattern is better defined and is as follows:

(*a*) The fully ductile energy beyond maximum load diminishes as width increases.

(*b*) As temperature goes below a certain limit this energy value drops well toward zero.

(*c*) In very wide plates this drop occurs at about the same temperature limit as before, but as width is reduced the limit moves downward, and at an increasing rate below a width of 16 thicknesses.

The detailed explanation of these facts in terms of the relative extent of zones E and D is not yet clear. It may well be that in a specimen mostly lying in zone E a definite transition T_N may be identified, and perhaps when zone D predominates we can find a transition T_B that fits the case.

In none of the specimens of the other types is much known as to what happens when relative extents of zones E and D are varied. In the impact specimens, on which we are invited to pin our hopes, we cannot even separate energy in the preliminary phase from the total.

However there is hope that we may soon unravel the intricacies of zones E and D and transitions N and B in the various types of test specimen. And when we have done that we may be able to put together a better picture of what to expect in an extended structure.

Discussion by T. McLean Jasper

An interpretive report is a most difficult one to produce. Under certain circumstances we have much need of such reports and these should be produced by persons with a broad background of experience. Mr. Boardman should be particularly well equipped to make such a report. The purpose of an interpretive report is to reduce confusion and to clarify a difficult problem.

In testing for facts or in setting up tests to answer certain pertinent questions, it is needful that the machines, measuring instruments, specimens and the questions to be answered should be very carefully selected. If possible the method of testing should closely represent or simulate service-operating conditions. If possible, the tests should in a short period of time give the answer which can be trusted for a long service period.

One of the most confusing problems before us at present is with reference to crack resistance of engineering materials. There is no doubt that with the much increased tempo of our civilization we are facing the need for very strong materials at elevated temperatures, very tough materials at low temperatures and the most economical materials and designs at all temperatures. With such structures as springs we need materials with large amounts of resilience at all temperatures of operation.

A considerable degree of confusion seems to be centered around the application of the notch test. This type of test has been given a large place in the thoughts of many technical men. The effect of a notch in reducing the apparent endurance limit in various steels is well known, but because of the tediousness of performing such tests various static and dynamic notch tests have been devised as possible single-effort, short-time substitutes. It should also be understood that no well-trained designer deliberately puts notches into service structures. This is also true of the fabricator.

As far back as 1938 Messrs. Spraragen and Claussen made a review on notch impact tests of welded joints covering the period from January 1936 to January 1938. Reference is made to 175 different reports for this period. Since then the number of reports on notch testing have multiplied many times this amount, so much so that great confusion is apparent.

Recently a correlation of the reduction of area using a round bar with various types of notch tests has been made at Lehigh by Prof. Bruce Johnston and his associates. This promises to lead to a much simpler method of arriving at sane testing methods for selecting steels where we think we should have resistance to slow bending, impact bending, slow tension and impact tension with notches for such services as have to be so designed. This of course is not a substitute for notch fatigue. Figure 6 in Mr. Boardman's report shows the relation between per cent reduction of area and V-notch impact bending Charpy tests. This correlation seems to be rather good and presumes to show a relatively narrow band when transition temperatures for steels are involved. The writer does not think that such tests will help us with notch fatigue tests.

The transition temperature, as shown by the various notch tests, is sometimes considered as the temperature

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at which the data obtained shows a transition from a high to a low value. It is sometimes considered to be the temperature point at which the transition from brittle to ductile fracture or the reverse occurs. Again, it is considered to be the temperature at which the change from tensile to shear fracture, or the reverse, occurs. So far the discussion has applied more particularly to steel.

The correlation between the slow notch bend test in the Lehigh report, shown as Fig. 5 in Mr. Boardman's report, when compared with transition temperatures is very good. Note on the above-mentioned Fig. 6 the average line as plotted for this particular relation is at a considerably more attractive value than that for the single-blow, impact-bending test. This is logical because one curve is obtained under static conditions and the other under dynamic conditions. Neither, however, represents notch effects on fatigue limits.

The above conditions may be satisfactory for correlation purposes and the appropriate static per cent reduction of area may be used as requirements for the common pressure vessel steels if the notches and specimen dimensions have been properly selected. This, of course, is very difficult to do and it is believed that it would be uncanny if the selection in the present tests has been made for the appropriate values. The reason for saying this is indicated in Fig. 1 of this discussion, which has been borrowed, for reference purposes, from the report by Armstrong and Gagnebin, published in Volume 28 of the *Transactions of the American Society for Metals*, dated 1940. It shows a series of transition temperatures of two steels: one a low-carbon steel and the other a low-nickel steel. Each transition temperature for each steel is the result of a different notch sharpness. The remaining metal below the notch in each case was of the same dimensions. The notch is a V and the bottom of each different V sharpness has a radius which varies from 0.009 to 0.25 in.

For the carbon steel the notch transition values vary from 0° F. to about −200° F. as the notch bluntness increases. For the nickel steel the notch transition values vary from about −60° F. to below −300° F.

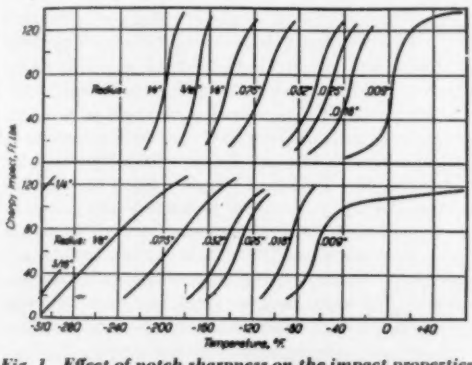


Fig. 1 Effect of notch sharpness on the impact properties of a carbon and a nickel steel

as the bluntness of the notch increases. It would seem, therefore, that the transition temperature values may be at a large number of temperature values and if the notch selected for the Lehigh tests is the right one, it would be so with unusual luck.

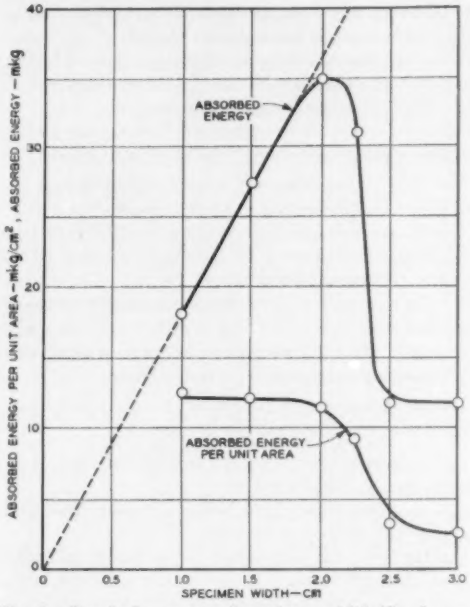

ABSORBED ENERGY
ABSORBED ENERGY PER UNIT AREA
ABSORBED ENERGY PER UNIT AREA – mkg/cm², ABSORBED ENERGY – mkg
SPECIMEN WIDTH – cm

Fig. 2 Absorbed energy and specimen width (Steel composition: 0.43% C, 0.16% Si, 0.36% Mn)

Figure 2 of this report is borrowed from Fig. 1 of the report of D. M. Moser of Essen. This diagram is from the Association Internationale pour L'Essai des Materiaux, Congress de Zurich 6–12, September 1931, and is contained on page 389 of Volume 1 of the final report. The steel is the same in each case, the notch is the same in each case, the depth of the specimen is the same in each case, but the widths of the different specimens for the plotted points vary from 1 to 3 cm. You will observe that as the width increases from 1 to 2 cm. the value of absorbed energy goes up and thereafter at 3 cm. width it reduces to below the value for 1 cm. width. The lower curve shows the energy absorbed per unit of area involved in the fracture. These tests were made at normal atmospheric temperatures. It would seem, therefore, that the width of specimen also has to be selected by a very sagacious group of people. A different notch bluntness could very well change the values shown in actual amount as well as in the relative amount.

Figure 3 of this discussion is a table which is borrowed from the same volume of the Congress de Zurich and from page 395, and is a discussion of Dr. Moser's paper by Dr. V. Jares of Prague. In this case it represents three different steels in which the notch test specimen has the same width but the notch varies

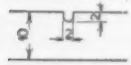
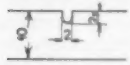
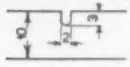
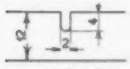
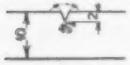
TYPE OF STEEL		N	M	P
ANALYSIS	%C	0.09	0.10	0.06
	%P	0.022	0.122	0.223
AVERAGE IMPACT VALUES-mkg/cm²				
NOTCH SHAPE				
		18.5	16.2	12.0
		18.9	15.2	10.7
		21.4	12.1	0.7
		25.8	13.6	0.5
		18.2	2.3	0.5

Fig. 3 Effect of notch shape on impact strength of three steels

in depth and one of the specimens is 12 cm. deep instead of 10 cm. deep. It will be noticed that Specimen N shows consistent values for the five notches shown, Specimen M has less consistency and Specimen P has the least consistency in energy absorbed. The difference shown in the material analysis is that of varying amounts of phosphorus. I suppose that an optomistic investigator would say that the difference in values of phosphorus was the cause. Even I might say this if I trusted implicitly this type of test. I am, however, using this diagram to indicate that the notch depth can have considerable effect in producing the values shown. For Steel P it will be noticed that the area exposed for breaking of the specimen type No. 1 is the same as for the specimen type No. 4 in the column below "Notch Shape" yet in specimen form No. 1 the average of the test results is 12.0 and in specimen form No. 4 it is 0.5. They both have the same notch width and the same depth and area of fracture.

The writer, therefore, in this discussion is hard boiled and is opposed to allowing technical men to decide matters involving valuable considerations on such a frail test as the notch impact value of materials without a much more directed and logical background for using such values. I have said the word "frail." I would also use the terms fragile, poorly selected, not conforming to service conditions and a lot of others. This test now has been available for a large number of years. This does not mean that it may not reach maturity in another long period of time, but it has so many vagaries that it is like putting faith in a roulette wheel to win valuable results at the present period of writing.

There is one item in Mr. Boardman's report to which I wish to take exception without even knowing how well his statement is backed up by reliable data. It is his caution item on page 427-s in THE WELDING JOURNAL of September1950, and states the following:

"Some of the results reported by the subcommittee on cold-formed heads indicate that a yield point obtained by cold working may, after aging, drop back appreciably toward its original value. Therefore, designs based on yield points obtained by cold working should be used only when the permanency of the raised yield points has been established."

If this were essentially true, the suspension cables on the Golden Gate Bridge in San Francisco whose yield strength has been raised by cold work to, I believe, over 200,000 psi. represents something which may indicate a grave hazard to those using it. The wire cables to mine hoists are also in the same category. Wire-wound and auto-frettaged guns are also hazards greater than expected. Even shrunk-on pulleys and crankshaft yokes and all of our railroad car wheels are pressed on with very large prestressing.

It is not my purpose to state even the more severe services of the use of cold work in the direction for use. I object to the implication in the form stated and believe it can start a witch hunt of which we have had too many.

*Author's Reply**

The comments received are helpful in clarifying and high lighting the most important features, establishing proper perspectives and opening up new avenues of thought and discussion.

H. O. Hill and T. M. Jasper have justifiably criticized the unqualified Caution against designing on yield points obtained by cold working until their permanency has been established. The following more careful wording of this Caution expresses the Author's understanding of the unofficially reported results:

"Caution: Some of the results unofficially reported by the Subcommittee on Cold-Formed Heads show that the yield point after cold working was higher and remained higher than it was before cold working, but varied with time, first rising to a maximum, and then dropping back nearly to the value it had immediately after cold forming. Therefore designs based on yield points obtained by cold working and aging should be used only when their permanency has been established."

Mr. Hill, who is Chairman of the Subcommittee on Cold-Formed Heads, and, therefore, is in very close touch with the work on which the Caution is based, recommends this wording:

"Caution: Some of the results reported by the Subcommittee on Cold-Formed Heads indicate that a yield point obtained by cold working may, after aging, increase for a period and then drop toward the value obtained by cold working. Subsequent testing over a period of time will be necessary in order to determine whether the higher yield strength obtained by cold working is dissipated. In the welding zones, of course,

*. These statements reflect the views of the members of the Committee of the Fabrication Division, P.V.R.C. of the Welding Research Council who cooperated with Mr. Boardman in the preparation of the original report.

the heat due to welding will destroy all gain in yield strength obtained by the cold working. Therefore, designs based on yield points obtained by cold working should be used only when the permanency of the raised yield points has been established."

Dr. Jasper decries the Caution as alarmism and cites cables of suspension bridges, mine hoists and wire wound guns, auto-frettaged guns, shrunk-on pulleys, crankshaft yokes and pressed-on railroad car wheels as pretty convincing evidence that yield strengths obtained by cold working are reliable for engineering purposes. However, the author believes that it should not be accepted without proof, that these examples are directly comparable with those of the Subcommittee on Cold-Formed Heads which involve cold pressing, bending and welding.

Certainly the official report of the Subcommittee on Cold-Formed Heads will be eagerly awaited.

Frank W. Davis expresses hope that reduction in cross-sectional area of tensile specimens at room temperature will displace the Charpy impact test at service temperature as the criterion of the suitability of ferrous materials for low-temperature service. Although he does not say so, it is likely that he also hopes that the reduction in cross-sectional area of tensile specimens will prove to be equally adaptable to nonferrous materials to which both the A.S.T.M. and the A.S.M.E. Boiler Code Committee recognize that the Charpy and Izod impact tests are inapplicable.

Mr. Davis criticizes the first paragraph of the Summary—particularly the statement that "even the most ductile material, according to measurements on unnotched laboratory specimens tested at room temperature, fails brittlely under conditions of low temperature or restraint preventing plastic flow" as not true of nonferrous materials. Of course he is right; the entire test program of the Fabrication Division, which is the subject of the Interpretive Report, had to do with carbon steels only.

H. Liessenberg says many more tests are needed to get for the Engineer full data on strain and temperature effects on steels. He implies that these effects may be helpful or harmful depending on their recognition and intelligent utilization. The recent extensive advertising of Carilloy T1 by the Carnegie-Illinois Steel Co. indicates that he is correct. This material is a quenched and tempered low-carbon alloy steel, having a yield strength of the order of 100,000 psi., and is reported to retain, after considerable cold working and after welding, ample toughness for pressure vessel service at low-winter temperatures. This almost appears too good to be true and supports Mr. Liessenberg's opinion that much more can be learned about what strain and temperature can do to steel.

Doubtless steel makers are already following to some extent the practice suggested by Mr. Liessenberg of taking advantage of the regular chemical and physical variations in the ingot by making different grades of steel out of different parts of the ingot.

Very practical may be his question as to why the higher yield point and greater strength of thin as compared with thick plates in the same heat are not recognized in material specifications and applied in designing. Although the still prevailing practice is to vary the chemistry with thickness to maintain the strength, there are indications of a trend toward maintaining the chemistry conducive to good welding and varying the physical properties with thickness. General acceptance of this trend would, for example, permit use of an appreciably higher design stress for $^1/_8$-in. than for 2-in. thick pressure vessel shells of the same A.S.T.M. quality, provided the relatively higher yield point and strength of the thinner plates could be conclusively shown to persist during fabrication, including welding and stress-relieving.

Mr. Liessenberg makes a plea for an exhaustive investigation of the relative merits of the various preheating, postheating and cold-straining treatments of welded joints in all steels. This is a large order, as he realizes, and would include the slow cooling, after welding, from 500° F. to room temperature, suggested by Mr. Spraragen, and by the work of Dr. A. E. Flanagan as reported in the September 1950, issue of THE WELDING JOURNAL under the title "Low-Temperature Cooling Rate Effects on the Ductility of Arc Welds in Mild Steel."

William Spraragen sizes up the situation in his usual direct and able fashion. He starts by stating that the Interpretive Report will accomplish little unless something is done about it. Then he points out how vessels for low winter temperature service could be improved by:

1. Making the steel pass an acceptance test like the Kinzel slow notch-bend test which, as the Interpretive Report Summary states, "could be made to include all of the factors affecting a weldment, including thickness, prestrain and welding."
2. Streamlining the vessel.
3. Using preheat or postheat, or both, if the steel or joints would be notch sensitive without such treatment.

If Mr. Spraragen were a dictator he could put the first of these measures into effect at once but, quoting from the Interpretive Report, "no major change along this line can be brought about without the active and wholehearted cooperation of user, steelmaker, fabricator and writer of construction and safety codes. The key man is the user; if ever he becomes sufficiently concerned about things as they are to consistently write into his requests for bids stipulations requiring tougher steels, they will be furnished and soon come into general use."

A structure is best engineered when it costs the least to make it just good enough for its intended use over the expected service life. The highest type of engineering consists in thus striking the proper balance between safety and cost. This problem of balance is involved in the question of material quality at issue which, short of

a dictatorship or a series of major failures, is not, in the author's opinion, going to be settled soon but rather by an extended period of thought, discussion, education, negotiation and laboratory and experience research.

Captain Roop, in his customary stimulating but somewhat facetious and occult manner, presents an excellent review of the various 'oughness tests—the Charpy, Lehigh, Navy, Penn State (Schnadt) and wide centrally and transversely notched—and sums it all up by saying "we still don't know how to recognize good steel when we have it" but that "we know steels are variable and we know what to do about it."

These statements the author questions. Intellectually, we may know what to do about the variability of steel, as Mr. Spraragen suggests, but practically we don't for the simple reason that failures are so few that industry does not now appear willing to bear the increased cost of more closely controlled steels.

Are we unable to recognize good steel when we have it? The author thinks that we can at least grade steels in the order of their suitability for cold winter service. We have no doubt about the adequacy of nonferrous materials for such service for they change little with reducing temperature and, if suitable at room temperature for pressure vessels, are also suitable at subzero temperatures. We have not found plain carbon steels with properties unchanged by low temperature and know positively that some steels are bad for winter use but good for room temperature use.

Surely we are able to distinguish cast iron from steel plate and to design accordingly. Captain Roop says "the only good steel is steel that will make a good structure." Under this definition the most notch-sensitive A.S.T.M.-A285 steel is a good steel if the structure of which it is made is properly designed and fabricated. The truth is that good structures can be made of a wide variety of steels provided the special properties of each kind are recognized and utilized, or guarded against, depending on their nature.

Captain Roop knows that if nickel steels, and low-alloy steels, and quenched and tempered steels (like Carilloy T1) cost no more than ordinary carbon steels, and were equally available, they would quickly displace the latter. Why, then, does he say that we don't know good steel when we have it? Would it not be nearer the truth to say that it is the marginal steels—sometimes good, sometimes bad, which bother us most?

Captain Roop's rejection of the Charpy Impact Test as a means of predicting the behavior of large weldments by saying "now we are invited to believe that a Charpy specimen $^1/_8$-in. square contains more truth than a ton-size plate," and his questioning that the reduction in cross-sectional area of a tensile specimen at room temperature might be used in determining transition temperatures by saying "I have not yet seen a correlation chart between date of rolling and phases of the moon, but no doubt that too has been tried" were no doubt intended as humorously cryptic remarks. To the author it seems highly probable that if we had a real understanding of either the Charpy specimen or the ton-size plate, or even the tensile specimen, we would have a pretty good understanding of the structure too. They are all related—the Charpy specimen, the ton-size plate, the tensile specimen and the structure, whether it be a ship or a pressure vessel or something else, and each would tell the same basic story, as the others, if we could understand all that they have to say.

Captain Roop states that the wide centrally and transversely notched plate specimen is like two tear specimens joined at the notched edges and "is the only specimen here considered which permits wide variation of the relative extent of the zone of preliminary fracture." He implies that this specimen, unlike the Lehigh and Kinzel slow notch-bend specimens, does not determine a "ductility transition temperature" and a "fracture transition temperature." The author does not see why this is so for it seems to him that there probably is for each wide centrally and transversely notched specimen, a temperature at which the initial fracture and the extension thereof will be ductile, a lower temperature at which the initial fracture will be ductile and the extension thereof brittle, and a still lower temperature at which both the initial fracture and the extension will be brittle.

Dr. T. M. Jasper's comments are straight to the point, and of course correct with reference to the Caution against designing on cold-work-yield points which the author has discussed above in connection with H. O. Hill's remarks.

Dr. Jasper believes that per cent reduction of cross-sectional area of unnotched tensile specimens tested at room temperature is a much more consistent value of steel than any value obtained from notched slow-bend or notched impact specimens. Therefore he advocates greater use of the tensile reduction in cross-sectional area criterion of toughness, and much more work on notched specimens to try to reduce them to a dependable basis.

Dr. Jasper's comments have to do mainly with notched test specimens. His primary purpose apparently is to show clearly the great variability in results obtainable from such specimens by changing:

(*a*) The sharpness of the notch.
(*b*) The width of the specimen.
(*c*) The depth of the notch.

In view of this diversity of possible results, he remarks that "if the notch selected for the Lehigh tests is the right one, it would be so with unusual luck" and "It would seem, therefore, that the width of specimen also has to be selected by a very sagacious group of people" and, with reference to the notch impact test "it has so many vagaries that to trust it is like putting faith in a roulette wheel to win valuable results."

In making these statements, Dr. Jasper may have in mind attempts by some to correlate the behavior of the Lehigh slow notch-bend and the Charpy and Izod impact specimens with actual vessel performance.

If so, he must absolve the Lehigh staff for they merely used the Lehigh slow notch-bend test as a tool in studying the reactions of two steels to various thermal and cold-straining treatments, and they then compared the results with those of Charpy tests on the same steels. They never claimed correlation of these tests with vessel behavior. Moreover, Dr. Jasper's views appear to add weight to the following excerpt from the Summary of the Interpretive Report:

"He (the Engineer) cannot see how a specific little laboratory specimen, with a specific method of loading, can in any way be representative of a whole vessel wherein are many notches both metallurgical and geometrical, each notch with its own special environment, history, residual stress system, and potential loading to propagate failure."

It seems to the author that Dr. Jasper must believe in and approve of some acceptance tests for steels even though the values to be met are largely and necessarily arbitrary. Also, it is certain that he is quite aware that the regular A.S.T.M. acceptance tests for A285 steel give little or no information as to its suitability for low winter temperature services, whereas either a notch impact test or a Kinzel or Lehigh slow notch-bend test would grade the samples in the order of their adaptability to such services.

The comments of H. B. Oatley and F. V. Hartman call for little discussion. Their generally commendatory remarks are appreciated. Mr. Hartman may be confused a bit because the Interpretive Report professes to present the background for the work of the Fabrication Division, report that work, and interpret it but is subject, of course, to the large personal bias of the author, who, although aided by an able committee, was allowed by them to write as he pleased.

Walter Samans wrote exactly the kind of commentary that the author would expect of him. As a man of vast engineering experience, and as the first chairman of the P.V.R.C., he takes an objective view of the work of the Fabrication Division, of the Interpretive Report, of the present status of the pressure vessel industry and of its future. He points out that:

1. The Interpretive Report can cover only the initial phases of the general P.V.R.C. program, and in comparison to work done by others.

2. The pressure vessel industry needs much more information to round out good rules of design for vessels of special alloys and for large field-assembled vessels.

3. The program to date has included a review of past performance and the attempt at Lehigh to get by test a systematic record of the effects of various thermal and cold-straining operations on two selected carbon steels.

4. The hydrostatic test, in addition to proving tightness, may be found useful to equalize peak stresses in regions of stress concentration.

5. He is not wholly in sympathy with the author's belief that the Engineer "longs for tougher steels, than are now available, at prices which he can afford."

6. Even with steels as they are, the future can be viewed with confidence, provided proper checks are made on material, design, inspection and fabrication.

7. High stresses are not necessarily alarming unless they are associated with defects located where they may develop into failures.

8. The Engineer should do the best he can with steels now available.

9. Premium quality steels should be used where the conditions of service demand their use.

10. Basic data should be sought first; with it at hand, progress should be more rapid.

George Watts' comments are greatly appreciated by the author. They are helpful and sound.

There can be no logical quarrel with him in his opinion that some kind of a toughness test, preferably of the impact type at the lowest service temperature, should be required of steel intended for low winter temperature service; the only thing that prevents it is the fact that users generally have experienced too few failures to induce them to demand it.

Mr. Watts properly emphasizes the fact that each interested group has its own problems to solve and should concentrate on them. The Metallurgist and Steelmaker should keep on trying to make tough steel at reasonable cost for low winter temperature service; the User may in time acquire a willingness to pay the extra cost for such steel or find a way to offset it; the Engineer should streamline more as working stresses are increased; and the Fabricator and Inspector should see that this streamlining is in fact accomplished.

Especially gratifying is Mr. Watts' recognition of the difficult job which was undertaken by the Fabrication Division, and his appreciation of what has already been accomplished and of how much still is to be done.

Falling-Weight Impact Test of Welded Aluminum Alloy Plates

A new test for comparing the resistance of welded plates to shock loadings at various temperatures

by E. C. Hartmann

IMPACT tests of the Charpy and Izod types, which involve small specimens containing various types of notches, have long been used as one means of evaluating various metals, usually the ferrous metals. The interpretation of the results from these tests, however, has always been a difficult matter and their use in evaluating the resistance of engineering structures to shock loadings has been thoroughly discredited.* The only test that seems to have very much engineering significance, as far as resistance of assemblies to shock loading is concerned, is some type of test which simulates shock loading conditions on actual assembled parts. In the pressure-vessel field, for example, some investigators have fallen back on drop tests using actual full-size vessels.

Obviously, any attempt to conduct experimental work on full-size assemblies is likely to become expensive and very time consuming, thus precluding the use of such tests for extensive investigations of the many variables which might influence the result. In the field of low-temperature applications where some materials or types of construction might exhibit brittle tendencies, it appears particularly important that some relatively inexpensive, easily reproducible, shock load test of assemblies be available. Such a test would probably be a compromise between the testing of full-size assemblies and the testing of small coupon-type specimens. As a step in this direction, the Aluminum Research Laboratories has recently developed a drop-load test on welded plates which is described below.

Having available an impact test tower in which various sizes of weights can be dropped vertically through various heights, it was natural to incorporate this piece of apparatus in the test. This impact test tower is essentially a structural steel A-frame 24 ft. in height mounted on an octagonal base, 17 ft. across the flats, containing about 40 cu. yds. of reinforced concrete. A suitable electric hoist is mounted at the top for lifting the weights. Figure 1 is a photograph of this impact test tower. In the center of the concrete base directly in line with the striking point for the falling weights is a 4 x 36 x 36-in. steel plate set flush with the top of the concrete and anchored securely to it, thus forming an anvil against which any type of drop test can readily be made. The tower is provided at present with five

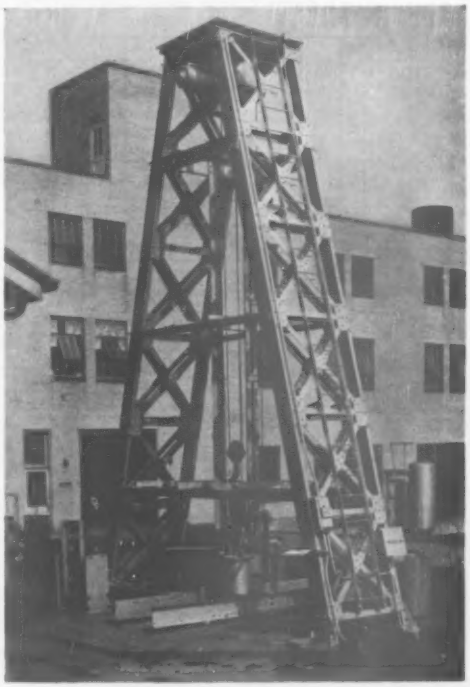


Fig. 1 General view of impact test tower at aluminum research laboratories

E. C. Hartmann is Chief, Engineering Design Division, Aluminum]Research Laboratories.

* A.S.T.M. Tentative Methods of Impact Testing of Metallic Materials, E23–47T (see Scope and Significance).

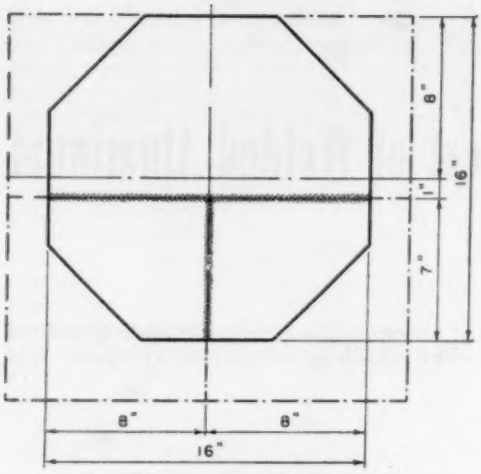


Fig. 2 Octagon specimen from welded plate

weights of 2000, 1000, 500, 250 and 125 lb., all of which fit the same set of guides without any adjustments. For this particular investigation, the 250-lb. weight was selected and was fitted with a special striking block on its lower face which terminated in a spherical nose of $^{3}/_{4}$ in. radius. With this striking block added the total weight was 257 lb.

The specimen used consists of an octagonal-shaped flat plate measuring 16 in. across the flats. For the main part of the work a $^{1}/_{4}$ in. thickness is used, although the test is adaptable to other thicknesses. The specimen can either be a solid plate or can be several plates butt welded together. Figure 2 is a drawing of the type of welded plate used in most of the tests made so far.

The plate to be tested is laid over a circular opening $11^{3}/_{4}$ in. in diameter which is centered under the guides so that the striking nose of the falling weight strikes the plate at right angles to its surface and at the center of the opening. The opening is formed by using a 12-in. extra strong steel pipe set on end and securely fastened to the base of the tower so that it will not bounce around under the influence of the striking weight. This tubular anvil or support is 30 in. high and has a $2^{1}/_{2}$-in. wide flange of welded steel construction around the top. Four vertically projecting steel lugs welded to this flange serve to center the octagonal flat plate specimens when they are laid on top of the anvil. It will be noted in Fig. 2 that the intersection of the two welds in the present type of specimen is off the center of the speci-

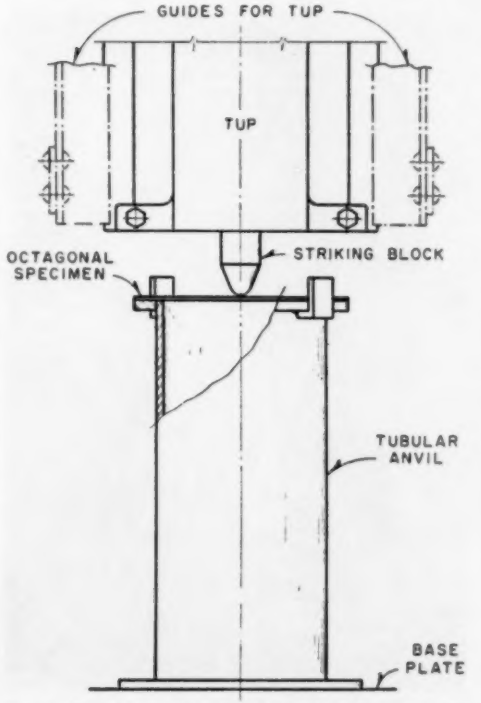


Fig. 3 Tubular anvil made from 12-in. extra strong steel pipe

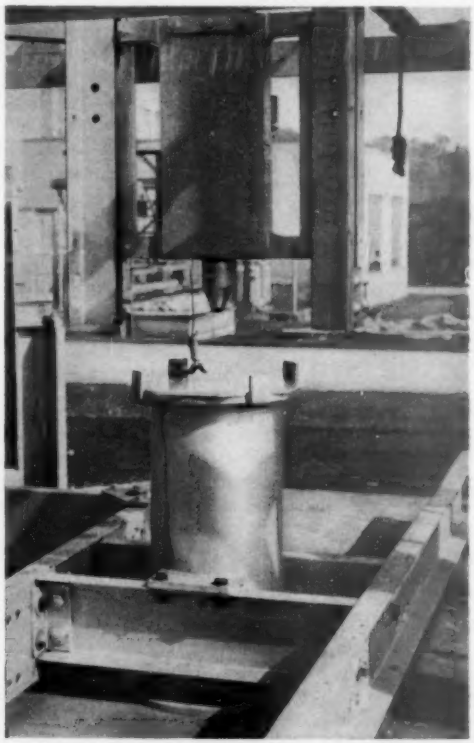


Fig. 4 Close-up photograph of anvil with specimen in place

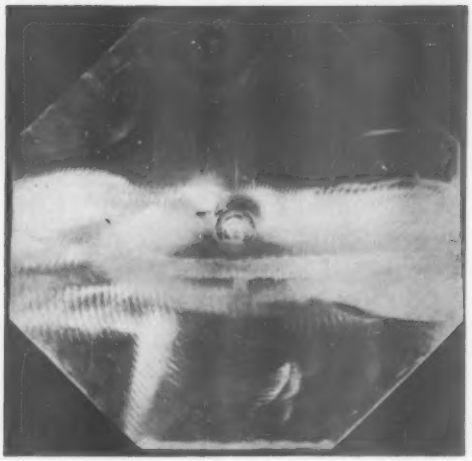


Fig. 5 Typical aluminum alloy specimen after test

Material 3S-H14 plate; ¼ in. thick. Height of drop, 48 in. Temperature, 74° F. Inert-gas-shielded tungsten-arc welds with 2S filler metal

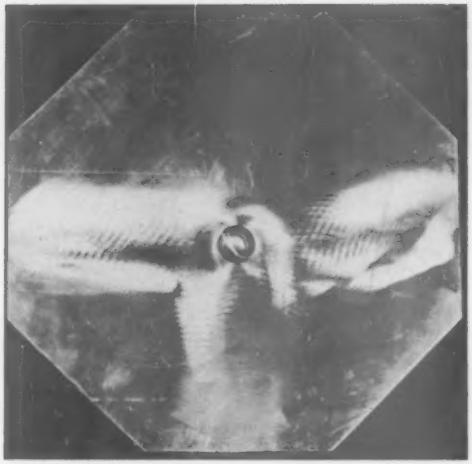


Fig. 6 Typical aluminum alloy specimen after test

Material 3S-H14 plate; ¼ in. thick. Height of drop, 72 in. Temperature, −280° F. Inert-gas-shielded tungsten-arc welds with 2S filler metal

men so that the falling weight does not strike at the intersection of the welds but 1 in. away. Figures 3 and 4 show the tubular anvil.

The procedure used in conducting the tests is as follows:

1. Set up the tubular anvil and align it so that it is centered under the falling weight.
2. Precool or otherwise prepare the specimens to be tested.
3. Raise the weight in the guides by means of the hoisting motor so that the height of drop (distance from the bottom of the striking nose to the top of the specimen) agrees with the predetermined value for the test in question.
4. Place the specimen on the anvil.
5. Release the catch permitting the 257 lb. to fall on the specimen.
6. Raise the weight in the guides to a sufficient height to permit removal and examination of the specimen.
7. Record all pertinent facts concerning specimen, such as nature and position of any fractures that have occurred. A close-up photograph is taken of the more important specimens.

It is obvious that very little can be learned from a drop test on a single specimen. The only logical procedure is to test a series of identical specimens each under a different height of drop to establish the critical height of drop at which first fracture occurs. This critical height of drop, or the equivalent in in.-lb. of energy, then becomes the basis of comparison between various series of specimens. For example, one may wish to compare the critical height of drop at room temperature with the critical height of drop at some lower temperatures. Comparisons can also be made between various alloys, welding methods, filler metals,

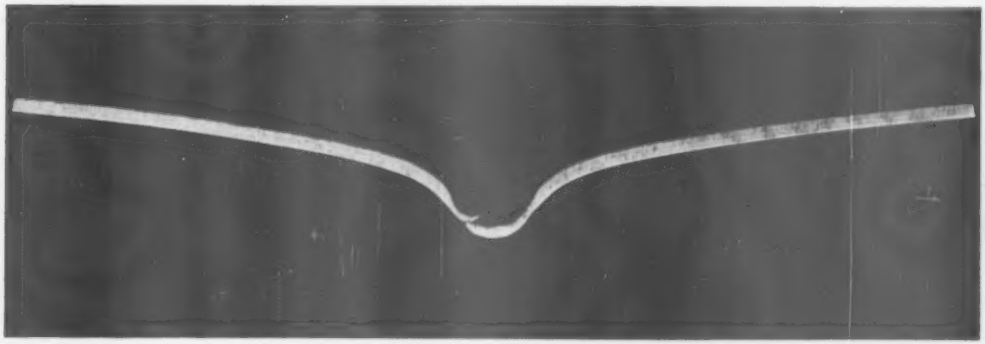


Fig. 7 Cross section of typical aluminum alloy specimen after test

Material 3S-H14; ¼ in. thick. Height of drop, 66 in. Temperature, 76° F.

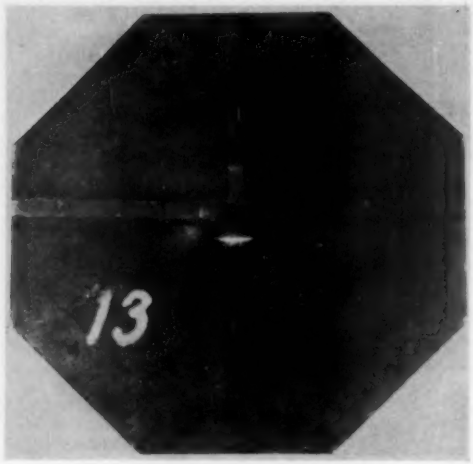


Fig. 8 Typical steel specimen after test

Material, steel boiler plate. 1/4 in. thick. Height of drop, 144 in. Temperature 80° F. Metal arc welding with E6010 electrodes (Fleetweld No. 5)

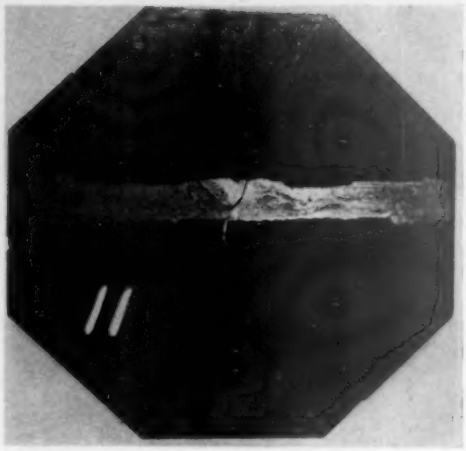


Fig. 9 Typical steel specimen after test

Material, steel boiler plate. 1/4 in. thick. Height of drop, 6 in. Temperature, −226° F. Metal arc welding with E6010 electrodes (Fleetweld No. 5)

heat treatments, welded vs. solid plate, weld bead removed vs. not removed, etc.

Work along the above lines is under way at Aluminum Research Laboratories using the method of test described above. The tests made to date have demonstrated clearly that aluminum-manganese alloy plates (A.S.T.M. B178 alloy M1A), both welded and unwelded, exhibit the same increase in strength and toughness at low temperatures that has been so well established for various types of monoblock specimens.* Comparative tests on mild steel plates, both welded and unwelded, have confirmed the fact that such plates behave in a very brittle manner at low temperatures. The results of some of these preliminary tests on aluminum-manganese alloy plates (A.S.T.M. B178 alloy M1A) and steel are illustrated in Figs. 5 through 9.

A word of caution is probably in order concerning certain features of the above test. It is evident that if any appreciable portion of the energy of the falling weight is dissipated in friction in the guides or as a result of lack of rigidity of the anvil, the results obtained would be difficult to duplicate on some other apparatus having these variables present to a different degree. An apparatus might be set up which would be entirely satisfactory for comparative tests where all tests were made on the same apparatus, but such apparatus might be entirely unsuited for making comparisons with tests made under other conditions. With this in mind, it is highly recommended that where a test of the above type is desired, considerable care should be taken to use a free falling weight, in loosely fitted lubricated guides and that the anvil be of adequate proportions, resting on a massive, solid base.

Where direct comparisons of test results are desired, the dimensions of the specimens and supports should be substantially identical on any two sets of apparatus. It is probably not quite so essential that the weight of the falling *tup* be identical in the two cases provided the results are stated in terms of in.-lb. rather than height of drop. It should not be overlooked, however, that striking velocities may have some influence on results so that wide variations in the sizes of falling weights should be avoided.

The test described above appears to be a reasonable compromise between full size tests and tests of small notched specimens. It is believed that comparative results obtained in such a test will prove very useful in predicting the effects that may be expected in full size assemblies under service conditions and in selecting fabrication procedures which will result in satisfactory performance under shock-load conditions.

The method described herein was developed as part of the work of the Engineering Design Division of the Aluminum Research Laboratories under the direction of R. L. Templin, Chief Engineer of Tests and Assistant Director of Research. The testing of the steel, and aluminum specimens was done by F. E. Rebhun, Research Engineer.

* "A Review of Information on the Mechanical Properties of Aluminum Alloys at Low Temperatures," by K. O. Bogardus, G. W. Stickley, and F. M. Howell, National Advisory Committee for Aeronautics Technical Note No. 2082, May 1950.

Explosion Bulge Test Studies of the Deformation of Weldments

Semiworks-scale testing of full welds in heavy plate under combined stress conditions such as prevail in structures and the significance of the findings in evaluation of weld performance

by Carl E. Hartbower and William S. Pellini

Abstract

A method has been developed for semiworks-scale testing of full welds in heavy plate under combined stress conditions such as prevail in structures. The test features the bulging of welded plate in diaphragm fashion. Uniform loading of the test plate is accomplished by means of an air blast set up by the detonation of an explosive. By modification of bulge geometry it is possible to obtain a wide range of stress fields.

Photogrid deformation studies of prime and butt-welded plates, 3/4-in. thick, have been made on spherical and ellipsoidal bulges which provided conditions of balanced (1:1) and unbalanced (0.8:1) stress fields. The test weldments consisted of a firebox-grade steel joined by means of single-pass submerged-arc welds and also by manual double-V butt welds. The welds investigated provided conditions of closely matching and of overmatching weld metal-parent plate flow strengths.

It has been demonstrated that the stress and strain states imposed by the loading conditions are not accepted as such by the weld joint. Depending on the overmatching characteristics of the weld and its geometry, a system of stress and strain entirely foreign to the remainder of the structure may be developed in the weld and near weld regions.

The significance of these findings is discussed in terms of weld performance evaluation.

DEVELOPMENT OF EXPLOSION BULGE TEST

Background

IT IS generally recognized that simple uniaxial stress conditions seldom, if ever, prevail in structures. Regardless of the gross conditions of loading, the design engineer is ordinarily faced with vector resolutions of loads involving either biaxial or triaxial stress fields. Inasmuch as quantitative engineering design data are presently available only in terms of simplified uniaxial loading tests, considerable effort in the field of applied mechanics has been expended in investigating the behavior of metals under multiaxial stress conditions. These investigations have been of two general types:

(*a*) Tube or bulge tests, which provide essentially biaxial loading conditions.

(*b*) Notch tests, which develop a high order of tensile stress triaxiality at the notch apex. There are no proved experimental procedures by which controlled triaxial loading (all stresses tensile) may be performed.

Briefly, it has been determined that stress conditions which are essentially biaxial do not change appreciably flow resistance or ductility in comparison to uniaxial stressing. Variations in the balance of such stress fields serve principally to modify the algebraic sign and direction of reference strains. Triaxial tensile stress fields on the other hand are known to increase flow resistance and decrease ductility. The effects are pronounced even at low average levels of triaxiality. The unfortunate requirement of a notch has tremendously complicated the interpretation of "triaxial" tests. To date, the factors which determine the degree of triaxiality of notch tests have not been resolved. It is not possible therefore to designate material properties in terms of definite triaxial stress conditions. In view of this limitation, the engineering field is forced to rely on the unreliable procedure of empirical correlation with service performance for the utilization of notch test data.

The welding engineer is in a particularly unfortunate position since very little is known of the performance of full welds except in simple uniaxial tension. Thus, even the most approximate form of empirical correlation between the performance of notched weld tests (as represented by the bead-on-plate weldability tests) and full welds in service is not possible.

It appears imperative at this time that a part of the welding research effort be dedicated to furthering the study of full weld performance. The Hatch Corner and Box Girder investigations, with the related notched, bead-on-plate weldability test studies, represented a specific type of strictly empirical approach to the performance of full welds in complex structures. The empirical correlations which resulted from these studies have been largely inconclusive, owing partly to the few structural tests which were preformed and partly to the complexity of the performance interpretations which were required. Retrospectively speaking, it appears that too great a jump was made from the simplified bead-on-plate laboratory tests to full welds in complex structures. The basic difficulty has been and remains the lack of a suitable semiworks-scale test for investigating the performance of full welds. One of the real needs of the welding field at this time is a relatively inexpensive structural test of full joints featuring a simple geometry which will permit testing under controlled loading conditions. Such a test may be viewed as the intermediate step required to tie the results of laboratory metallurgical and weldability tests to the performance of weldments as component parts of structures.

This report is concerned with the development and initial use of a semiworks-scale test of full welds. The initial use made of this test entailed a fundamental study of the deformation characteristics of various weld joints.

Basis for Choice of Test Method

It has been stated previously that the experimental techniques which are available for the investigation of the behavior of metals in controlled stress fields are limited to biaxial loading and include:

Carl E. Hartbower is Metallurgist and **William S. Pellini**, Head, Metal Processing Branch, Metallurgy Division, Naval Research Lab., Washington, D. C.

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1. Tube tests—which require axial tension concomitantly with internal hydrostatic pressure.

2. Bulge tests—which require fluid or gas pressure on edge-supported diaphragms.

Tube or bulge tests therefore provide a possible means by which full welds may be tested, within certain limitations, under controlled loading conditions. The limitations are that the weldment be in the form of a tube or plate and that the imposed load control be biaxial. There are relative advantages and difficulties to be considered in arriving at a choice between these test methods. The tube test has the advantage of providing uniform strain conditions over a wide test area. This advantage is partly theoretical inasmuch as excessively long tubes are required to provide a central zone sufficiently removed from the grips to eliminate end-bending effects. The disadvantages of the tube test are related to complex equipment required and experimental difficulties of setting up and conducting the tests. Tube tests are extremely expensive and have been primarily limited to fundamental research in the field of applied mechanics. It is interesting to note that a limited study of the performance of welds has been conducted by tube tests.[1] This investigation resulted in the only prior report of the performance of welds in controlled biaxial-load fields. The results of these tests are discussed in detail in a later section of this report.

The advantages of bulge tests lie in the simplicity of equipment and experimental procedures required. The principal disadvantage of these tests is the relatively small area of pole region which may be classed as effectively under uniform strain. The bulge test has been utilized by a number of investigators for the study of the flow and fracture of metal sheets under combined stresses.[2,3] The bulges are ordinarily produced by hydraulic pressure applied to a test diaphragm clamped over a circular or elliptical opening. It is well known that spherical bulges developed from a circular diaphragm represent a condition of balanced biaxial stress and that the stress in ellipsoidal bulges is unbalanced with the major stress in the minor axis direction and the minor stress in major axis direction. The degree of stress unbalance developed in ellipsoidal bulges is a function of the relative ratios of the two principal axes of the ellipse but is not in exactly the same numerical ratio.

It should be noted that bulge tests of thick plates develop bending conditions which give rise to a reaction stress* component in the thickness direction. Although the value of this third stress component cannot be determined directly, it may from theoretical considerations and from observations of bulge fracture performance be considered minor in comparison to the two principal stresses in the plane of the plate. The important feature to be noted for such bulge tests is that performance of the full weld may be evaluated in terms of exacting control over two of the three possible principal stress directions. Such tests offer particular promise for the investigation of the effect of weld orientation in relation to imposed biaxial load fields. Inasmuch as biaxially loaded plates, with or without a minor third stress component, are fairly common in structures (ship plate weldments for example), the information obtained has direct applicability in addition to fundamental research value.

The controlled biaxial stress conditions made possibly by bulge tests and the simplicity of the test weldment provide the desired features for a semiworks-scale test if sufficient force can be developed for bulging heavy-plate weldments. Snellings' procedures[4, 5] for direct explosion testing demonstrated that explosives could be utilized for such a purpose. Snellings' technique of contact explosion does not provide the uniform loading required for a true bulge test. Recourse can be made to offsetting the explosive and shaping the charge to a wafer so as to provide for a flat explosion wave of uniform intensity. It should be noted that removing the explosive from direct contact with the test plate has the advantage of minimizing the shock wave or brisance effect of explosives which is inherently variable and difficult to control. With offset conditions, the effect of the explosive is primarily that of rapid loading by very high gas pressure. The gas pressure from an explosion is inherently more reproducible and requires a minimum of procedural control. Contact explosion conditions, on the other hand, require exacting brisance control, which can be obtained only with specialized explosives.

* Reaction stresses are defined as stresses resulting from restraint to plastic flow. Such stresses are ordinarily present in regions of severe strain gradients such as exist at notches or at thick sections undergoing severe bending. Standard texts such as Timoshenko's *Strength of Materials* and Nadai's *Plasticity* treat the bending problem quantitatively only for conditions such that the stress in the thickness direction is sufficiently small to be ignored; i.e., for bending of members such that the radius of curvature is very great compared to the thickness. Such simplified "plane stress" conditions (A. Nadai, *Plasticity*, McGraw-Hill Book Co., New York, p. 182 (1931)) do not apply for drastic bending conditions.

Technique of Explosion Bulge Testing

A standard military demolition explosive (Block M3 Composition C3) was used for all tests reported herein. This explosive, which has the appearance and consistency of soft wax, is readily shaped to a circular or elliptical wafer of the size and shape of the opening in the die.

The test weldment, which consisted of a 20- x 22-in. plate produced by butt welding two 10-in.-wide plates, was placed over a circular (r = 6 in.) or elliptical (a = 7.5 in., b = 4.8 in.) opening cut in a 4-in. thick armor saddle plate. The die opening was chamfered to provide smooth entry of the bulge into the die cavity. The explosive wafer was then located at a distance of 12 to 24 in. (depending on the standoff required) above the test plate. An expendable pasteboard box was used as a support. The arrangement is shown in Fig. 1. Detonation was by means of an

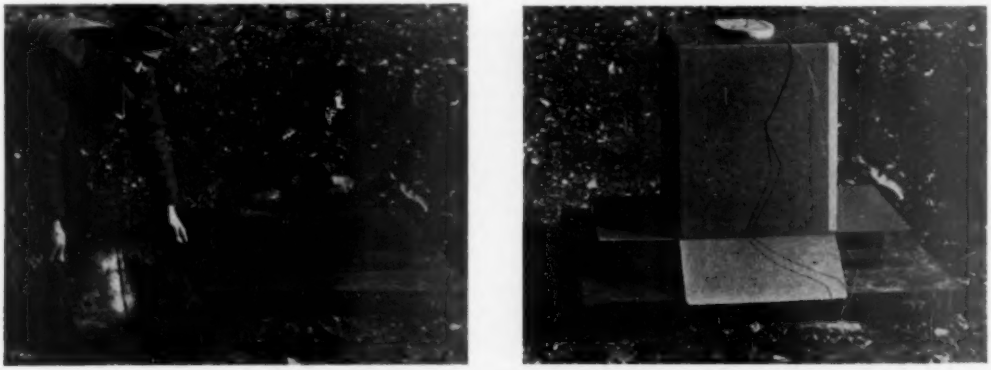


Fig. 1 Explosion bulge test equipment illustrating simplicity of test procedures

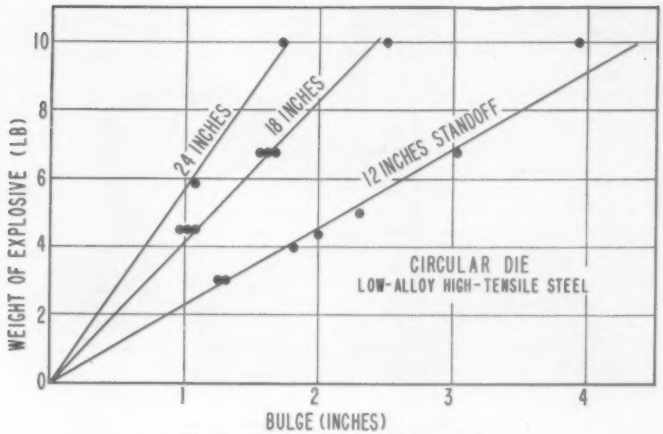


Fig. 2 Control of bulge deformation

electrical primer. The unsupported area of the plate was approximately 28% of the total area; the remainder of the plate was effectively clamped to the armor die by the gas pressure of the explosion, thus providing the required "hold-down" without need of a bolting ring. The effectiveness of the "hold-down" was evident from observation of bulged plates, which remained perfectly flat over the supported area.

The simplicity of this test procedure permits testing at temperatures other than ambient by the simple expedient of soaking test plates in a controlled-temperature cabinet, removing them as required, and placing them over the die for test. Critical temperature control is readily obtained by spot-welding thermocouples to the plate, and detonating at required temperature. For most work, however, the temperature drop during the time required for locating the plate and explosive is insignificant.

It was determined that the size of bulge could be exactingly controlled by varying the weight of charge and "standoff." Figure 2 presents, an empirical chart of bulge depth versus weight of charge with standoff a parameter as determined for a high-tensile low-alloy steel. The plot of points of repeat tests indicates the high degree of reproducibility obtained. The excellent control possible with explosion loading tests was also shown in the weld strain studies to be described.

WELD DEFORMATION STUDIES

Choice of Weldments and Scope of Studies

It has long been almost axiomatic that a theoretically perfect weld requires (*a*) exact matching of mechanical properties between weld deposit, heat-affected zone (HAZ), and base material, and (*b*) freedom from flaws. This general premise is presently being challenged by some investigators on the grounds that it is not realistic to expect attainment of this double goal in practice. A solution which has been proposed entails the use of weld deposits overmatching the flow strength of the parent plate, and featuring high notch toughness. In view of the diversity of opinion which prevails on the relative merits of matching versus overmatching and the importance of this question to the welding field generally, it was decided to direct the bulge test to a study of this problem. As a first approach it was deemed desirable to obtain basic information as to the nature of plastic deformation over the entire weld-joint zone of matching and overmatching weld deposits. The studies included balanced (1–1) and unbalanced (0.8–1) stress fields with weld orientations varied relative to the major stress in the case of the unbalanced stress fields. Tests were also performed on prime plate material to provide a reference strain-field condition. All strain measurements were made at arbitrary levels of general strain well below the critical strain producing fracture. Inasmuch as the present studies were concerned only with strain-distribution characteristics and not with fracture, no attempt has been made to hypothesize fracture modes. The relation of stress state to fracture is a subject of continuing research.

Material

The material used in this investigation was taken from a single heat of commercial silicon-killed firebox steel plate, 3/4 in. thick, ordered to Specification A201 Grade A.

Chemical analysis, %:	
C	0.18
Mn	0.44
Si	0.24
P	0.013
S	0.039
Tensile properties:	
Yield point, psi	38,540
Tensile strength, psi	64,380
Elongation, %	29.9

Welding Procedure

As part of this investigation it was considered desirable to include a special research-type weld of the simplest possible geometry; viz., a single-pass butt weld with heat-affected and fusion-zone demarcation lines vertical with respect to the plate surface (Fig. 3). Thus, any cross section parallel to the weld would contain a single microstructure and would consequently be a plane of uniform physical properties.

The joint preparation and welding technique used to obtain the desired weld

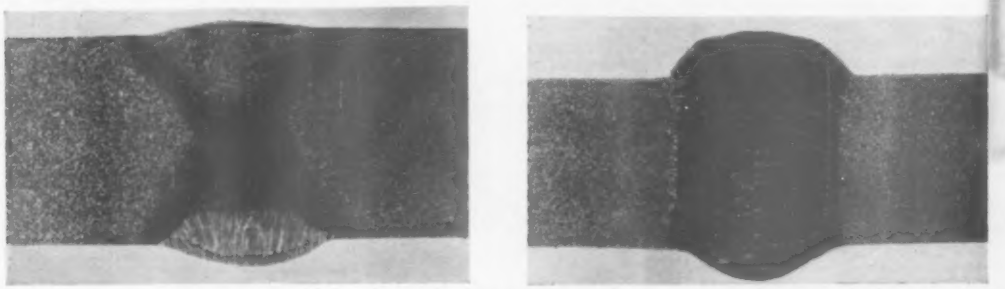


Fig. 3 Geometry of weld deposits. (left) Manual multipass; (right) submerged arc-single pass

geometry consisted of machine-beveling the plate to a 30° included angle and submerged-arc welding at 1300–1325 amp., 32–33 v. and 12 in. per minute travel. A refractory "backup" was used for support. Two types of weld deposits were produced with this square geometry: a low-alloy deposit (0.13% C, 2.0% Mn), which is widely used for welding low-alloy high-tensile steels; and a high-alloy submerged-arc deposit of composition similar to SAE 6130. A commercial welding composition grade 20 size 20 x 200 was used for both welds.

For comparison with the research-type submerged-arc weld, manual-multipass, E12016, butt welds were prepared with a geometry similar to that commonly used in ship construction. The plate edge preparation consisted of a 60° double-V joint (Fig. 3).

Explosion Procedure

The unwelded bulges and all welded bulges, except for the high-alloy submerged-arc weld, were formed at 60° F. using 4 lb. of explosive at 12-in. standoff. In order to deform the high-alloy weld without causing fracture, the testing temperature had to be raised to 180° F. and the standoff increased to 18 in. This change in test conditions resulted in a somewhat smaller bulge.

Measurement of Strain

Strains were determined by measuring the distortion of a 20 line-to-the-inch grid applied to the test plate by a photogrid process (Details of application appear in the Appendix.)

Measurement of grid distortions was accomplished by means of a microscope mounted on a micrometer slide which in turn was supported by three adjustable legs (Fig. 4). Two sources of error were involved in the strain readings, viz., the inherent error in the spacing of the grid lines (approximately ±0.0005 in.), and the error of the observer in centering the microscope crosshair on the grid line and reading the vernier (again approximately ±0.0005 in.). The scatter resulting from these errors was found to be excessive if the gage length of the strain determinations was taken as one grid spacing. Compensating errors in the grid spacing reduced the scatter band to a reasonable width at a gage length of 0.100 in. which was the gage length used throughout this study.

Microtension Test

As part of the problem of interpreting the deformation characteristics of welds, information is required concerning the individual flow properties of the various components of a weld joint. Inasmuch as there is no established method for testing the very small volumes of metal involved, a

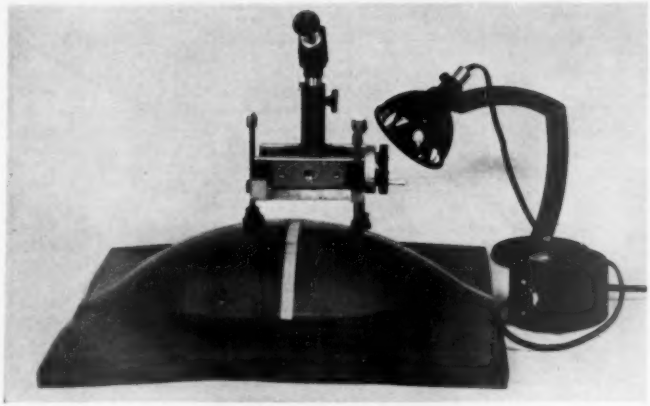


Fig. 4 Strain measurement

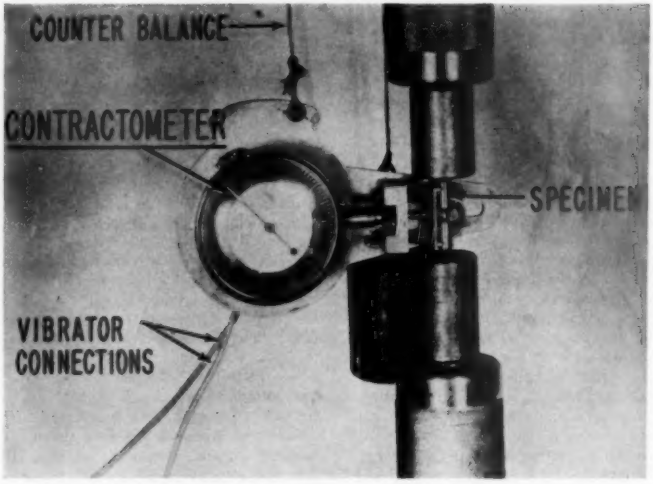


Fig. 5 Details of contractometer and microtensile specimen

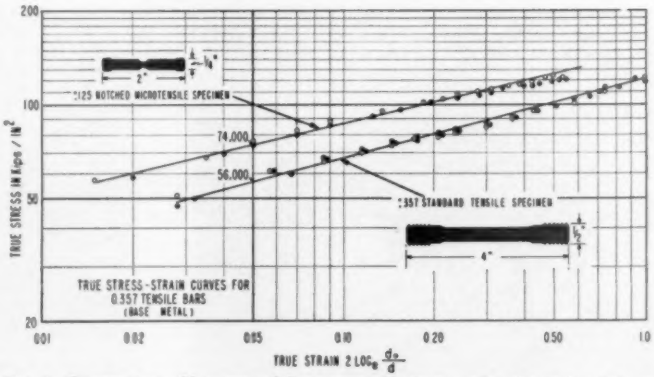


Fig. 6 Comparison of base metal flow curves illustrating the effect of notch on flow strength

small notched tensile specimen was designed, together with a contractometer device for obtaining continuous readings of the reduction in diameter at the base of the notch. Figure 5 shows the contractometer and a specimen in place for test. It was thus possible to obtain true stress-strain or flow curves of small volumes of metal in the order of 0.002 cu. in. The effect of the notch of the microtensile specimen in introducing triaxiality and thereby raising flow strength may be deduced from Fig. 6 which presents comparison base metal true stress-strain flow curves as determined with a standard 0.357-in. tensile specimen and with the notched microtensile specimen.

DISCUSSION OF STRAIN DISTRIBUTIONS

Unwelded Prime Plate

The discussions which follow have been restricted to the conditions of strain state and absolute strain level at the pole of the bulge. The pole is defined as the region at the apex of the bulge which does not show strain distortions arising from hold-down or edge effects. Hold-down effects may be noted as peculiarities in the strain curves developed as the edge regions of the bulges are approached. These conditions are recognized as specific to bulge mechanics and therefore not pertinent to the present discussions. Absolute uniformity of strain level would be desirable over the entire pole region; but, as previously stated, bulge tests inherently approach but do not achieve such a condition. For purposes of this study it was considered necessary that a region of essentially uniform strain be developed which would be of sufficient size to encompass the weld, HAZ, and a portion of the unaffected plate in the test weldments.* This requirement was met in both the circular and elliptical bulges.

It should be noted (Fig. 7) that the elliptical die geometry develops a bulge having an unbalanced biaxial strain field of 1–2 (0.050/0.100) ratio. If the plate is considered essentially isotropic, the stress field may then be deduced† to be in the order of 0.8–1, i.e., the stress along the major axis is 0.8 of the stress along the minor axis. It should also be noted that the component of the strain parallel to the minor axis (major strain) is consistently designated as e_1, and the component parallel to the major axis (minor strain) as e_2.

In the case of the circular bulge, the convention of designating the radial strain as e_1 and the tangential strain as e_2 was adopted. The circular bulge (Fig. 8) develops a balanced biaxial strain field (0.070/0.070) which is the result of a

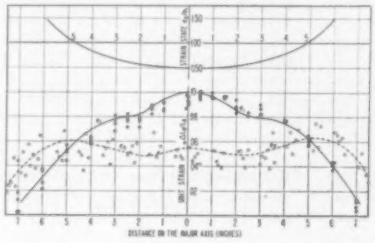
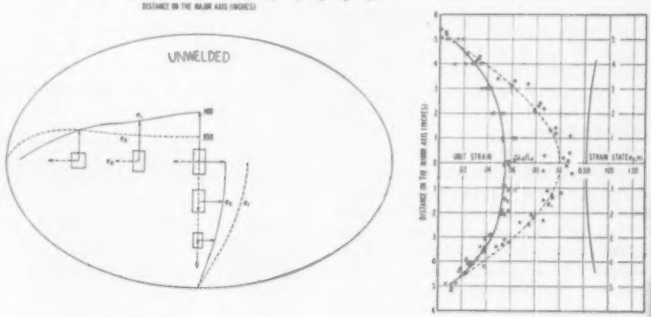


Fig. 7 Distribution of strain in an unwelded elliptical bulge



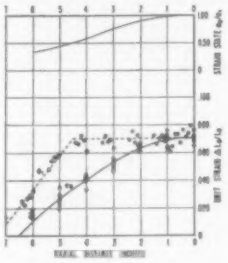
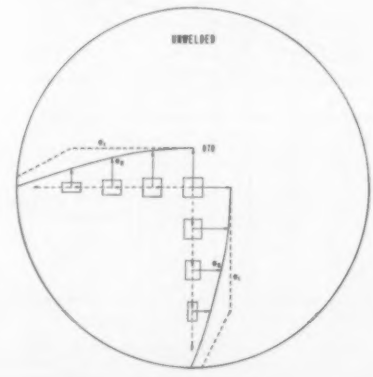
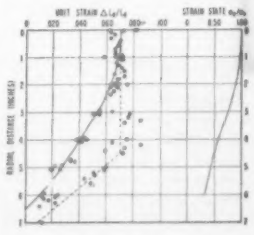


Fig. 8 Distribution of strain in an unwelded circular bulge





* In consideration of the normal scatter, the strain in the pole region was considered to be essentially uniform if the deviation of the faired-in curve from the strain at the pole was no greater than 0.01 in./in.

† Reciprocal calculations for any stress or strain ratio may be made by means of the following formulas:

$$S_1 - \tfrac{1}{2}(S_1 + S_2) = D\,E_1$$
$$S_2 - \tfrac{1}{2}(S_1 + S_2) = D\,E_2$$
$$S_3 - \tfrac{1}{2}(S_3 + S_1) = D\,E_3$$

where S_1, S_2, S_3 = principal stresses, E, E_2, E_3 = principal strains and D = plastic modulus. Accordingly, it may be calculated that balanced biaxial stress fields result in balanced biaxial strain fields, and unbalanced biaxial stress fields produce unbalanced strain fields. The strain ratios of unbalanced strain fields, however, are not simply in the ratio of the principal stresses. Thus, a strain ratio of $E_2/E_1 = 1/2$ represents a stress ratio $S_2/S_1 = 0.8/1.0$; $E_2/E_1 = 0/1$ represents a stress ratio $S_2/S_1 = 0.5/1.0$.

balanced biaxial stress field. The simplified sketch of strain distribution at the lower left of Figs. 7 and 8 is intended to provide a means of ready reference and orientation for the reader. This sketch includes schematic elements which are scaled to represent grid distortion. Squares indicate equal extensions in all directions and rectangles indicate greater strain in one direction. In Figs. 10–16 the schematic for the unwelded bulge is included so that direct evaluation may be made as to the effect of the presence of the weld. Note that Fig. 7 is unique in that the strain distribution for the full length of both axes is shown, though only half of each axis is represented in the schematic. The ratio of strains e_2/e_1 defines the strain state and shows the degree of unbalance of the combined strains. The ratio has been computed from the distribution curves for e_1 and e_2 and is plotted against distance on the major and minor axes in each of the figures showing distribution of strain.

Welded Plates

The introduction of welds generally resulted in marked modification of the strain characteristics in the weld and near-weld regions as compared to the same position in the unwelded bulges. The plate regions removed from the weld zone, however, matched the strain characteristics of the unwelded bulges. It should be noted that modifications of strain fields in the weld and near-weld zones indicate concomitant modifications of stress fields. This is so because the principal strains bear a rigorous relationship to the principal stresses as described by the reciprocal calculations presented previously. Thus, the stress-strain conditions in the weld-joint area may differ considerably from the imposed stress-strain conditions in the homogeneous portion of the bulge. These localized changes are strictly the result of introducing heterogeneous zones having different properties from the remainder of the test area.

In order to interpret the strain-field patterns in terms of the intrinsic strength properties of the weld-joint zones, measurements were obtained of the relative flow strengths of the weld deposit, various positions in the HAZ, and the prime plate using the microtensile technique described in the previous section. These data are presented in the form of flow curves in Fig. 9, and summarized in the following table as relative levels of flow strength at a fixed level of strain, in this case arbitrarily chosen as 0.05 strain.

Table 1—Relative Flow Strength (Psi. at 0.05 Strain) of Weld Joint Zones

	Weld	*HAZ*	*Plate*
Low-alloy submerged arc	81,000	78,000	74,000
High-alloy submerged arc	117,000	78,000	74,000
E12016 manual	140,000	78,000	74,000

The application of these data for the purpose of understanding the nature of weld deformation is simplified by utilization of the concepts of "Equivalent Load" and "Equivalent Strain" conditions. According to these concepts, each stress of the biaxial field is visualized as acting separately and developing certain specific effects which depend on the orientation of the stress to the weld. Any stress (major or minor) applied in a direction transverse to the weld is deemed to place the weld, the HAZ, and the prime plate in a state of "Equivalent Load"; i.e., as a first approximation all component parts of the weld joint must perforce support the same load (but not the same stress because of section diminutions resulting from flow). The strain in these various components may, however, differ widely depending upon their relative flow strengths. Any stress applied parallel to the weld is deemed to place all weld zones in a state of "Equivalent Strain"; i.e., as a first approximation all components must strain essentially the same amount, but the stresses in the various components may differ widely depending upon their relative strength levels. It will be shown in the discussion of weld flow characteristics which follows that the observed strains are in accordance with these concepts.

Low-Alloy Submerged-Arc Weld

The low-alloy submerged-arc weldments consisting of a single-pass, square-sided, butt weld with reinforcement ground flush

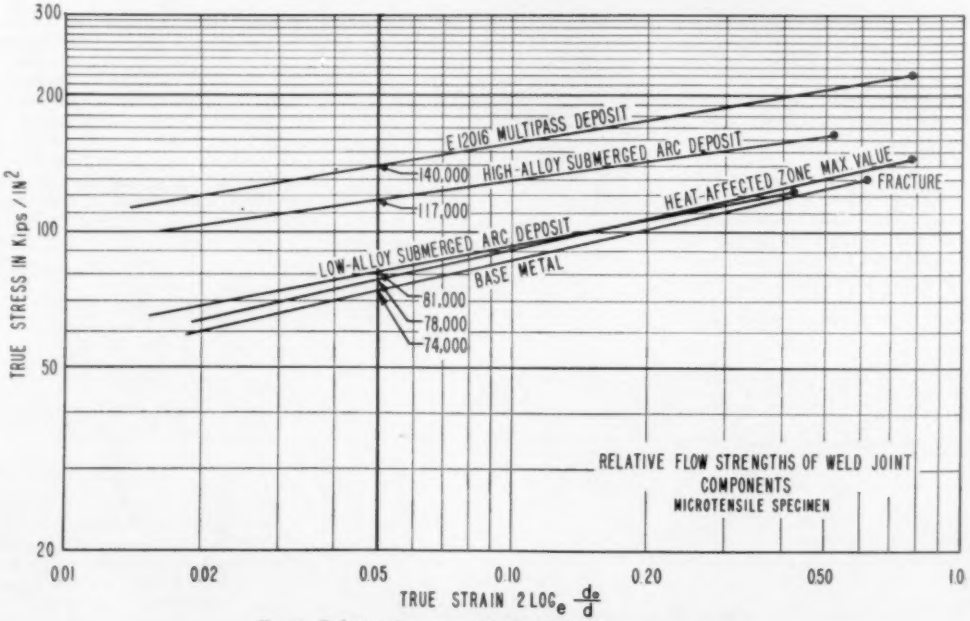


Fig. 9 Relative flow strength of weld joint components

were tested in three conditions: (1) Balanced biaxial stress. (2) Unbalanced biaxial stress with weld perpendicular to principal stress. (3) Unbalanced biaxial stress with weld parallel to principal stress. Pertinent data are presented in Figs. 10, 11 and 12.

These weldments represent close matching of weld-joint and prime-plate flow strengths. As listed in Table 1 the weld deposit and HAZ exceeded the plate flow strength by only 7000 and 4000 psi., respectively. It is interesting to note that this very small difference in relative flow strengths was sufficient to decrease or deconcentrate strain from the weld region in the "Equivalent Loading" stress direction (across weld) in each of the three tests. Figure 10 shows that the normal balanced (0.070/0.070 ratio) strain condition produced in the unwelded circular bulge has been unbalanced to a 0.040/0.070 ratio by the presence of the weld. The change to an unbalanced strain field in the weld denotes a change in the stress field from the imposed balanced biaxial stress to unbalanced biaxial stress with the major stress in the weld longitudinal direction. It is surprising that the strain deconcentration effects extend into the unaffected prime plate approximately $^1/_2$ in. beyond the edge of the darkly etching HAZ.*

Figures 11 and 12 show the effect of varying the orientation of the weld in the 0.8–1 unbalanced stress field of the elliptical bulge. A definite deconcentration of strain in the transweld or "Equivalent Loading" stress directions is noted in both tests. In the case of the weld located transverse to the major stress (Fig. 11) the 1–2 (0.050/0.100) strain ratio of the unwelded plate is changed to 0.050/0.085 ratio by virtue of deconcentration of the major strain. In the case of the weld located parallel to the major stress (Fig. 12) the deconcentration takes place in the minor stress direction thus decreasing the minor strain value. This results in a strain ratio of approximately 1–3 (0.030/0.100). In both of these tests it should be noted that the strain along the weld or "Equivalent Strain" direction is not significantly changed in value from that indicated by the unwelded plate in corresponding directions. Also, the strain deconcentration effects of the weld tend to extend outward beyond the weld into the unaffected plate as noted in the case of the circular bulge.

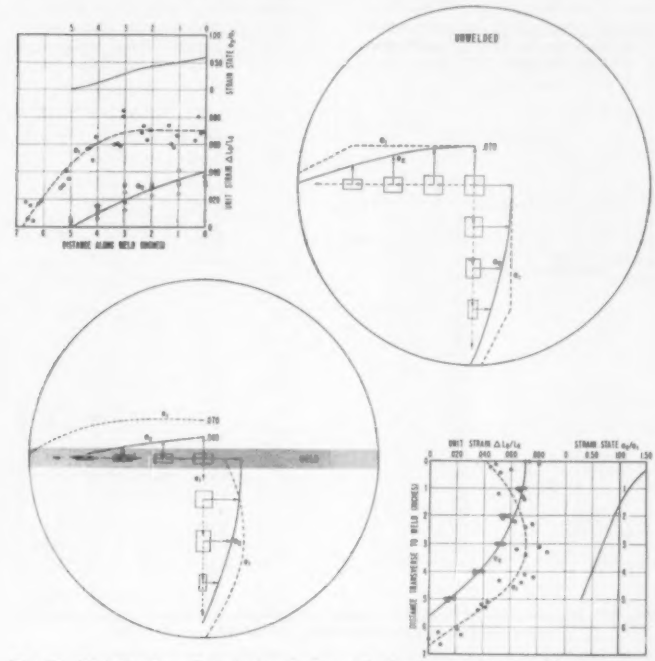


Fig. 10 Distribution of strain in a bulge with closely matching weld metal-base metal flow strengths (low-alloy submerged arc deposit)

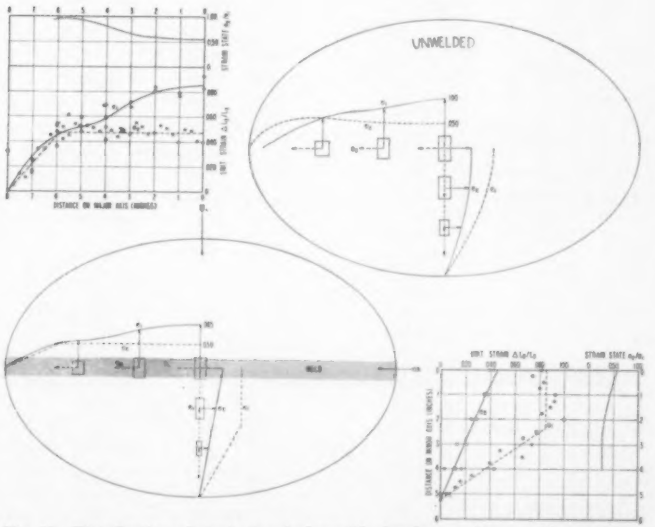


Fig. 11 Distribution of strain in a bulge with closely matching weld metal-base metal flow strengths (low-alloy submerged arc deposit)

High-Alloy Submerged-Arc Weld

The high-alloy submerged-arc weldments were similar to the low-alloy submerged-arc weldments in having the same square geometry and in being made with a single-pass technique. It should be noted, however, that the explosion test

* This condition is believed to arise from the restraint action (Poisson effect) extending out as reaction stresses from the weld region, which is in a less advanced stage of deformation through the thickness direction (ϵ_3 strain). Constancy of volume considerations dictate that the algebraic total of the $\epsilon_1 + \epsilon_2 + \epsilon_3$ strains equal zero. Inasmuch as the transweld strain is less than the corresponding strain of contiguous material and the weld longitudinal strain is the same as that of contiguous material, it follows that the (ϵ_3) thickness strain in the weld must be of lower-than-general value. This effect is distinctly visible as a relief of the weld in the case of strongly overmatching d2333 its.

conditions used for bulging were somewhat modified by raising the test temperature and increasing the standoff distance, as described previously, in order to prevent fracturing of the weld at the bulge size desired for strain measurement. Strict comparison on the basis of absolute magnitude of strain cannot therefore be made; comparisons based on ratios of strains are, however, considered valid. These welds overmatched the prime plate by approximately 43,000 psi. (117,000 psi. vs. 74,000 psi.). Tests were performed in unbalanced tension* with the weld oriented parallel and perpendicular to the principal stress direction (Figs. 13 and 14).

It is noted that with the major stress oriented across the weld, the resultant strain in the transweld direction (Fig. 13) was deconcentrated to the extent of unbalancing the strain ratio from 1–2 (0.050/0.100 unwelded) to approximately 3–1 (0.040/0.015) thus marking a complete reversal of the strain (and stress) field. In the case of the weld orientation which placed the minor stress across the weld Fig. 14, the strain deconcentration effect changed the strain ratio from 1–2 (0.050/0.100) to 1–8 (0.010/0.080). While exact comparison cannot be made, it should be noted that the values of strain along the welds are of approximately the same magnitude as the corresponding strains in the unwelded bulge; viz., 0.080 vs. 0.100 and 0.040 vs. 0.050 in the major and minor stress directions, respectively. The strain-deconcentration effect of the weld extends into the base plate for approximately the same distance as noted for the low-alloy weld.

It is interesting to note that comparison with the lower strength, square-sided, single-pass weld clearly shows a more severe deconcentration effect for the higher-strength deposit.

E12016 Weld

E12016 weldments consisting of multipass, double-V, butt welds with the reinforcement removed were tested in unbalanced tension with the weld oriented parallel and perpendicular to the principal stress direction (Figs. 15 and 16).

This weld represents considerable overmatching of the prime plate. As listed previously (Table 1), the weld flow strength at 0.05 strain exceeded that of the plate by 66,000 psi. (140,000 psi. vs. 74,000 psi). Severe deconcentration effects were noted in the transweld direction of both tests performed. In the case of the major stress acting across the weld (Fig. 15), the 1–2 (0.050/0.100) strain ratio of the unwelded bulge was modified to 1–1 (0.040/0.040) balance as the result of deconcentrations of the major strain. In the case of the minor stress acting across the weld (Fig. 16) the minor strain was reduced from 0.050 (unwelded) to 0.015; thus, the strain unbalance changed from 1–2 (unwelded) to approximately 1–7 (0.015/0.100). In either case (weld parallel or perpendicular to major stress) the strain along the weld was not significantly changed from the values noted for the un-

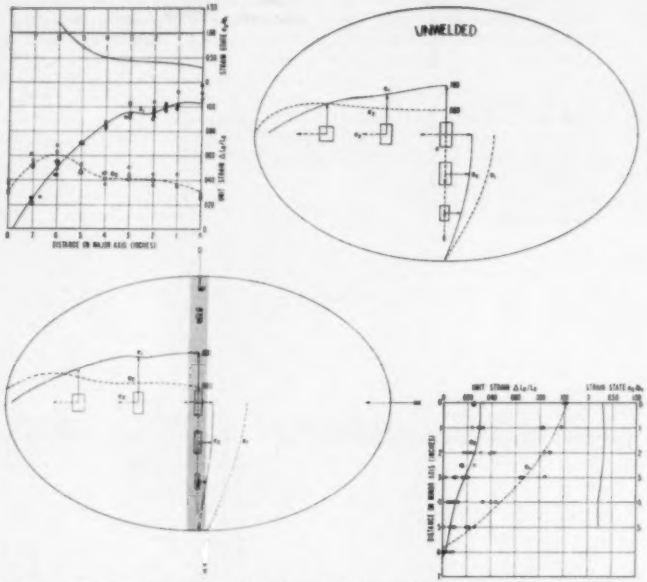


Fig. 12 Distribution of strain in a bulge with closely matching weld metal-base metal flow strengths (low-alloy submerged arc deposit)

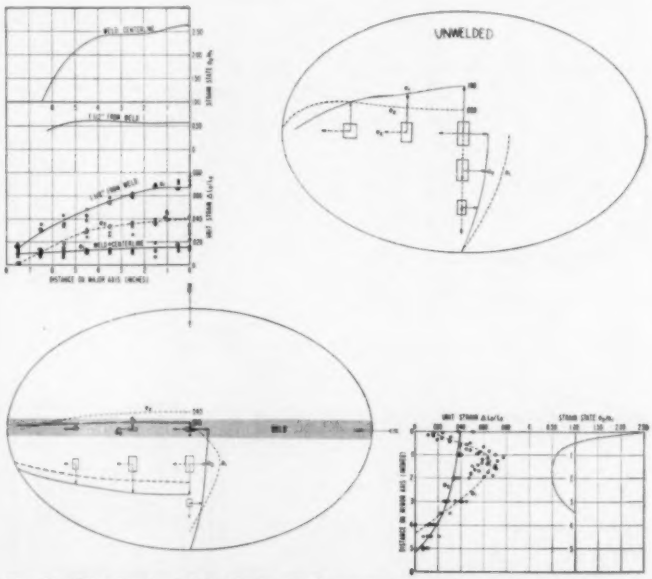


Fig. 13 Distribution of strain in a bulge containing a high-strength butt weld (high-alloy submerged arc deposit)

* Inasmuch as the data obtained for the low-alloy weldment with balanced tension (circular bulge) indicated the same general trends and characteristics as shown in unbalanced tension (elliptical bulge) subsequent weld tests were limited to unbalanced tension.

welded plate in corresponding positions and directions. A strain survey made 1½ in. from the weld and parallel to the weld (Fig. 15) further substantiates this conclusion. The strain deconcentration effect of the weld is noted to extend into the unaffected base plate for a distance of approximately ⅛ in. beyond the edge of the darkly etching HAZ.

Although the degree of overmatching of the E12016 weld was greater than that of the high-strength square weld, the strain deconcentrations in the transweld direction were significantly lower. It is believed that this behavior results from the square geometry of the lower strength weld. (See Fig. 3 for etched cross sections of the square and double-V welds.) It may be deduced that the V-geometry places the high-strength weld material in parallel loading with the lower-strength base-plate material, resulting in a combined strength of intermediate value; the square geometry obviously does not permit such a condition.

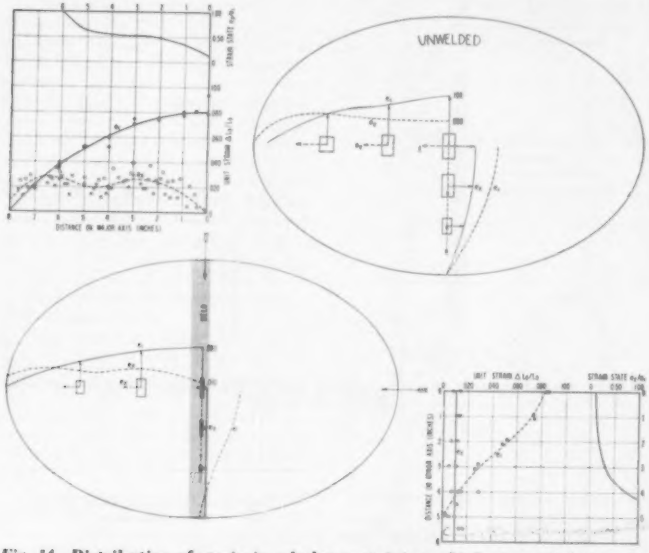


Fig. 14 Distribution of strain in a bulge containing a high-strength butt weld (high-alloy submerged arc deposit)

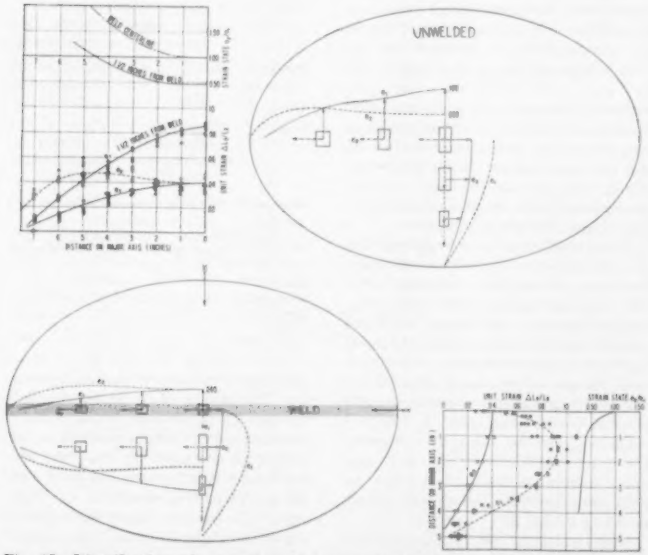


Fig. 15 Distribution of strain in a bulge containing a high-strength butt weld (E12016 electrode)

Summarisation of Strain Distributions

A generalized analysis of the strain distributions of closely matching and overmatching welds in biaxially loaded stress fields indicates the following basic pattern:

1. The presence of overmatching welds results in marked modification of the strain field not only in the weld deposit and HAZ zones but also outward into the unaffected base material.

2. The change in the strain field caused by overmatching welds is determined by a deconcentration of the strain component transverse to the weld. Weld strains in the direction of the weld length are not significantly affected. This mechanism appears to be general for biaxially loaded stress fields, and is independent of the orientation of the weld relative to the major stress direction.

3. The orientation of overmatching welds in unbalanced biaxial load fields determines the maximum and minimum values of the greatest deformation (principal strain) developed in the weld. A maximum value is reached when the weld is oriented in the direction of the major stress, and is always along the length of the weld regardless of relative overmatching characteristics. A minimum value of the principal strain is reached when the weld is oriented in the direction of the minor stress. However, the direction of the minimum principal strain varies with overmatching characteristics; it is ordinarily transweld but shifts to a longitudinal direction if overmatching and consequent deconcentration effects are sufficiently severe to reverse the strain field.

4. The degree of strain deconcentration produced by overmatching welds appears to be a function not only of the relative degree of overmatching but also of the geometry of the weld.

5. The strain modifications observed in the weld and near-weld zones may be translated in terms of modifications in stress fields. Generally, in keeping with the noted changes in strain fields, it may be deduced that (*a*) overmatching welds in balanced biaxial loading will develop highly unbalanced biaxial stress conditions, (*b*) overmatching welds in unbalanced loading will approach stress balance and even produce a complete reversal of the direction of major stress if the weld is placed in the direction of the minor load and (*c*) will develop increased stress unbalance if the weld is placed in the direction of the major load.

6. It should be noted that items 1–5 are specific to conditions entailing plastic deformation of weldments. In the elastic range the elastic strains of all components are determined by the elastic modulus, which is essentially invariant for steels. Accordingly, no modifications of elastic strains should be expected and the weldment should strain as if it were metallurgically homogeneous.

General Discussion

The problem of the performance of welds in structures is basically a problem involving the performance of welds under a great variety of stress conditions. If information were obtained as to the pattern of weld behavior under general conditions of stress, a rational basis for the evaluation of structural performance would be provided to the design engineer. Such an approach to the weld-performance problem requires the use of a semiworks-scale or structural-model technique by which weldments featuring practical full welds may be tested under a wide range of known and controlled stress conditions. Such a test should not be considered as a substitute for laboratory tests such as notched bead-on-plate weldability tests or the standard flat-plate A.S.M.-A.S.M.E. bend tests, but as a simplified structural test serving to link the results of the laboratory to structural performance.

The California tube tests[1] are an example of a structural-model approach. Full welds in tubes made from $^{3}/_{8}$-in. plate were tested in various biaxial stress fields. These tests required specialized weldments and equipment and were excessively expensive for comprehensive investigations.

The results of the California tests, although severely limited in number so that a general pattern of weld behavior could not be deduced, have great practical significance. These tests have shown that the mode of failure of weldments is specific to the stress system imposed on the weldment. Thus, the futility of any indirect empirical attempt to relate quantitatively the performance of welds in structures, *which may involve a number of weld joint designs and cover a spectrum of stress conditions*, to the performance of a single welded specimen, *featuring a simplified bead-on-plate and tested under a specific and single condition of stress*, was clearly indicated. This does not imply that significance may not be drawn from the performance of simple specimens in laboratory tests, but that the basic pattern of weld performance as a function of stress system must be known in order to evaluate the significance of such tests in terms of structural performance. Extension of bulge-test techniques to the testing of simple plate weldments provides a means by which structural-model tests may be conducted at relatively low cost and hence in sufficient variety to allow comprehensive investigations.

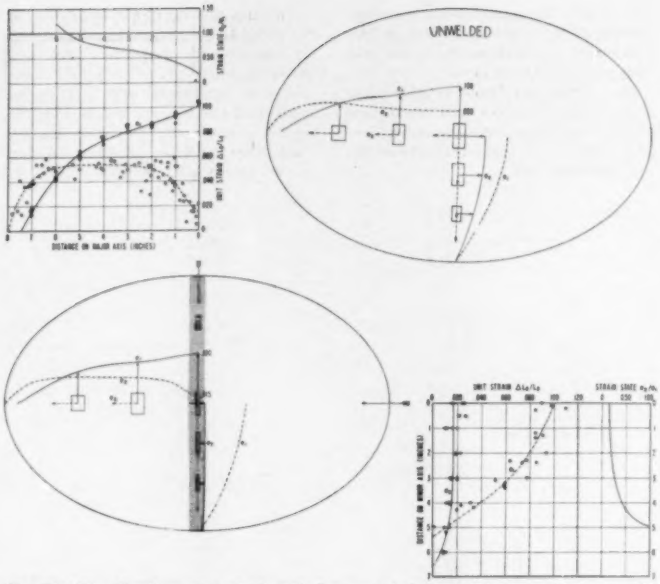


Fig. 16 Distribution of strain in a bulge containing a high-strength butt weld (E12016 electrode)

The application of the explosion bulge test to the study of the weld deformations has served to provide basic information requisite to a comprehensive approach to the fracture problem. It has been demonstrated that the conditions of stress and strain imposed by the loading conditions on the structural components remote from the weld joint are not accepted as such by the weld joint. Thus, depending on the overmatching characteristics of the weld and its geometry, an entirely foreign system of stress strain may be developed in the weld and near-weld regions. These effects obviously require consideration in any evaluation of weld performance as a function of applied stress conditions.

The method of explosion loading used in this investigation naturally raises questions as to the significance of bulge tests. The weld deformation studies of the slowly loaded California tube tests, which involved balanced and unbalanced biaxial loading similar to stress fields of the bulge tests, provide an opportunity to check the validity of the strain and stress reversals noted in the explosion tests. A numerical evaluation may be made by comparing the strain distribution in tube and bulge under balanced biaxial loading where the weld and plate combinations were closely matching (Table 2).

Exact numerical correspondence should not be expected, inasmuch as the bulge test weld was of square geometry while the tube test weld featured double-V geometry. The nature of the strain reversals, however, are in the same directions and of the same order. The transweld strain deconcentrations noted in the tube test featuring a 0.5/1 unbalanced stress ratio follow the pattern shown by the bulge tests. (Bulge tests were performed at 0.8/1 unbalanced stress ratio; hence numerical comparisons cannot be made.) The concepts of weld-deformation me-

Table 2—Comparisons of Strain Distributions

	Bulge tests	*Tube tests*
Materials:	$^{3}/_{8}$-in. plate, 65,000 T. S. Square submerged-arc weld: 7000 psi. overmatch	$^{3}/_{8}$-in. plate, 60,000 T. S. Multipass VV E6020 weld: 7000 psi. overmatch
Stress system:	Balanced biaxial tension	Balanced biaxial tension
Strain ratio*	Plate 1/1. Weld long./trans. 1/0.57	Plate 1/1. Weld long./trans. 1/0.8

* The strain ratios are as given in Fig. 10 and are hence specific for a deformation level of 0.07 in./in uniform strain. The strain ratios for the tube test held for a wide range of general deformation from approximately 0.05 in./in to 0.15 in./in strain.

chanics deduced from the bulge studies should therefore be considered to be general to weld performance and not specific to high rates of loading.

Further evidence of the general validity of the bulge-test data was obtained by a study of the strain distributions in slow-bend specimens containing the high-strength square weld used in the bulge tests. The subject weld was tested in longitudinal and transverse bend; comparison was also made with an unwelded specimen. In order to obtain uniform bending conditions over the test area of the specimen, four-point loading was employed. Figure 17 illustrates the severe strain-deconcentration effects (transweld strain reduced from 0.035 at $1^1/_2$ in. from the weld center line to 0.007 at the weld center line) developed in the weld region as the result of transverse loading. Longitudinal loading of the weld on the other hand indicated no deconcentration of weld strain. As in the case of the bulges, the strains longitudinal to the weld closely matched the longitudinal strains of the unwelded test specimen.

These studies collectively demonstrate the importance of weld orientation with respect to the principal stress direction in determining the degree of strain developed in welds. There are, therefore, interesting possibilities of application from practical as well as from laboratory viewpoints.

From an engineering viewpoint it would be desirable to take advantage of the wide range of strain levels which may be developed in a weld by intentionally orienting the weld in a favorable direction whenever feasible to do so. For uniaxial or strongly unbalanced biaxial loads, it is possible to reduce the value of the principal strain by orienting the weld transverse to the direction of principal load. In the case of balanced loads such manipulation is not possible.

From a viewpoint of conducting laboratory tests such as the standard A.S.M.E. Boiler Code, flat-plate, free-bend tests, which are aimed at actually testing the *ductility* of the weld deposit, it would appear necessary to test under the most severe weld-strain-producing condition. This condition should logically be that of a weld oriented in the longitudinal direction of the bend specimen. Since the tests are presently conducted using a transverse weld, severe deconcentration effects should be expected with overmatching deposits thus providing a condition highly favorable to the weld. With such a testing condition the strain burden would be largely transferred to the parent plate. It should be observed, however, that tests aimed at detecting gross weld flaws which are inherently oriented parallel to the weld, such as lack of fusion or incomplete penetration require transverse loading tests. Logically the purpose of the test should form the basis for the selection of loading conditions.

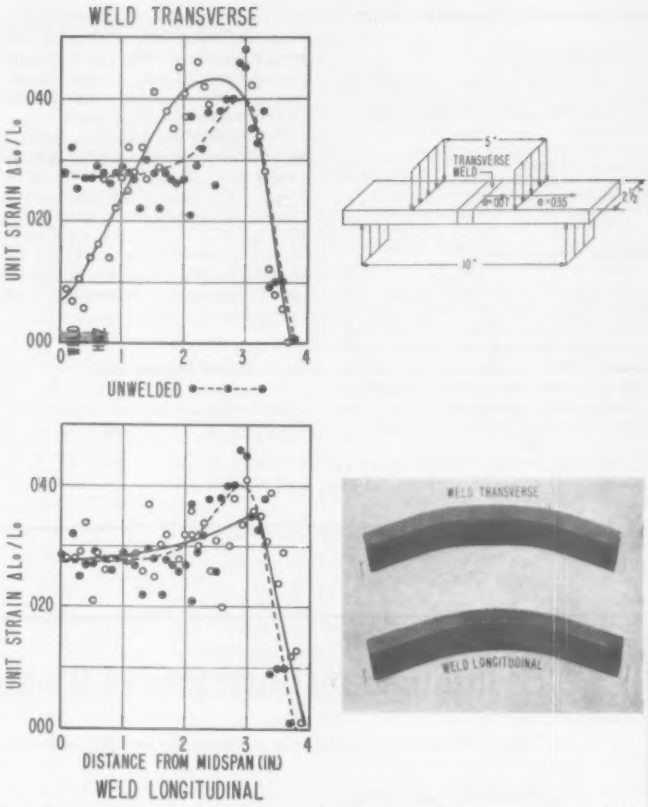


Fig. 17 Distribution of strain in a slow-bend specimen containing a high-strength butt weld (high-alloy submerged arc deposit)

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Appendix

TECHNIQUE FOR PHOTOGRID APPLICATION

Precision grids have been used by many investigators for the analyses of plastic strains (see the paper "Strain Analysis by Photogrid Method," by W. F. Brown, Jr., and M. H. Jones, *Iron Age*, 158, 50–56 (Sept. 12, 1946) for a thorough and excellent treatment of the subject). The application of the photogrid process to explosion bulge testing required some modification of procedure and particular attention to technique. The following section details the procedures which were evolved.

Materials and Equipment Required

Carbon tetrachloride.
No. 1 abrasive paper.
1% solution of ammonium hydroxide.
Black Gum contact emulsion (Dyrite).
Deep etch developer (calcium chloride).
Methanol.
Spray gun and filtered air supply.
Negative precision grid.
Vacuum printing frame.
Single 35-amp. carbon arc.
Developing and washing tanks.

Surface Preparation

The test plate was surface ground and then washed with carbon tetrachloride to remove any grease and oil deposited during grinding and handling. The plate was then rubbed with No. 1 abrasive paper to impart a cross-hatch pattern of minute scratches in the surfaces to be grided. As a final precaution to assure a clean surface, the plate was swabbed with cotton saturated with a 1% solution of ammonium hydroxide. The cotton revealed the presence of any foreign matter; swabbing was continued until the last vestige of stain had dissappeared.

The emulsion was applied by spraying six thin layers of emulsion using approximately 40 lb. pressure from a filtered air supply. If necessary the emulsion was thinned to a spraying consistency with distilled water. Care had to be exercised to obtain a uniform coating without the formation of droplets. Each layer of emulsion was allowed to dry thoroughly before applying the next layer.

Exposure and Development

The sensitized plate and negative grid was placed in the printing frame which consisted of an air-tight receptacle with a transparent flexible cover. By evacuating the receptacle the grid was clamped in intimate contact with the test plate by the flexible cover. The emulsion was exposed for 7 min. to the ultraviolet rays of the carbon arc lamp placed approximately $3^1/_2$ ft. from the printing frame.

Developing was accomplished by rubbing the exposed surface with a cheesecloth pad saturated with calcium chloride deep etch developer. The unexposed emulsion was removed by this operation leaving a sharp black grid on the plate. After the surplus developer had been removed by an air blast, the plate was submerged in a tank of methanol. The plate was then rinsed several times with clean methanol to eliminate any trace of calcium chloride. After drying in a filtered air blast, a thin coat of clear lacquer was sprayed over the grid as the preservative.

International Institute of Welding Bulletin

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Description—Abstracts of books, articles, trade catalogs and patents published through the world. Those coming from the countries of Western Europe are prepared by the welding society of the country of origin.

Numbers[1]—During 1950 each issue contained approximately 600 abstracts.

Classification system—The system has been specially designed in view of the special problems raised by the many affinities with other engineering subjects of welding. A table of corresponding indices for the universal decimal system exists.

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The Influence of Biaxiality on Notch Brittleness

Discussion by Wendell P. Roop

The most important fact hitherto known about "embrittling factors of a purely geometrical nature" is that they exist at all, and no clear reason for this fact is yet widely accepted. The vague idea that "restraint favors brittleness," though widespread, is not precise enough to do much good.

Also pertinent, however, is the fact that advance of a crack in the process of rupture is always preceded by a stage of crack formation. It is my own observation that local fracture in a notch occurs at an early stage and that a considerable interval, say most of the preliminary phase, is devoted to a gradual enlargement of the opening, with pronounced flow nearby. The choice between ductile and brittle modes of final rupture is not completed until this preliminary phase ends. Mr. Saylor Snyder has an excellent word for it: the "conditioning" phase.

Once a crack is formed the notch acuity is very high. It seems a gross violation of the principle of St. Venant that the presence or absence of metal at a distance from the notch of a hundred or a thousand times the length of its radius should influence the advance of the crack. Yet that is what is implied when we admit that the depth of the machined notch, or the width of the specimen (distance the crack must advance to complete the rupture) affects the ductile-brittle transition.

Many projects have been set up for study of the effects of depth, angle and acuity of machined notches on the behavior of the specimen in which the notch is cut. In the present project an ingenious novelty consists in adjusting the proportions of the notch so as to obtain a constant elastic concentration factor.

New and convincing evidence is given to show that even in the most brittle cases strain of the order of 5% precedes fracture. The influence of fracture exerted by the geometry of the machined notch must therefore be indirect, acting through intermediate events in the preliminary stages.

The more specific purpose of the present tests was to explore the effect of "biaxiality." It is a peculiar feature of the discussion that it is put in terms of two "biaxialities," one of them associated with thickness. This is a rather free paraphrase of the standard usage in which none of the three principal stresses is ignored.

An alternative analysis of the data is offered herewith based rather on the idea that the conditioning phase of fracture involves mainly a zone of metal near the apex of the notch whose relative extent is the most significant feature of the action.

When allowance is made for the size of the specimens, the thicker ones absorb less than a proportionate amount of energy in the fully ductile mode. This agrees with many other observations. It is explained by the fact that the conditioning zone is relatively greater in thicker specimens of equal width.

As to transition temperature, the curves of Fig. 14 would not be much changed if plotted on thickness directly. The result confirms that of Kahn and Imbembo (*Welding Research Supplement* April 1949). The thickness effects there were smaller than here, but in the same direction. The effect of increased thickness on ductility is due (*a*) to the inclusion of outer layers of the rolled plate in the thick specimens, a metallurgical cause, and (*b*) to the decrease in the ratio of width to thickness, a geometrical cause This last is stated in terms of a dimensionless ratio on the ground that a purely geometrical effect would not depend on absolute size unless some physical magnitude could establish a scale.

The directions of these two effects might be opposed. It is widely accepted that thick plate is more brittle than thin; when such a comparison is made at equal values of width-thickness ratio, the loss of energy absorption and rise in transition temperature are purely metallurgical effects, since the comparison is made on equal terms geometrically.

But if the comparison is made at equal values of width, as in the present tests, increase in thickness is decrease in ratio of width to thickness, and this is supposed to favor rather than to inhibit ductility. If transition temperature were plotted at constant width-thickness ratio instead of at constant width as in Fig. 14, the curve would rise more steeply with thickness. It would then show the full metallurgical effect of thickness, with no offset by the reduced relative width of the thicker specimens.

Curves of that sort have been plotted for the Swarthmore plate data and they show much less abrupt rise of the transition temperature than in the present tests, about 30° F. for a threefold increase in thickness. If plotted on constant width these curves would be even flatter, or might even drop away to lower values at greater thickness; they are not well enough defined to be clear on this point. But it is completely certain that the rise with thickness in the tests now under discussion is much steeper than in the Swarthmore plate data.

Among the various reasons that might be suggested for this the one offered by Mr. Vanderbeck in oral discussion refers to the difference in type of specimen. I quite agree with this, and think it possible to be more explicit in seeking to explain how geometrical differences might account for the observed effect. The explanation refers to the pattern of Luders lines.

Hitherto I have assumed that the width of a Luders band is about equal to the thickness of metal. The fact that we are now considering suggests that as thick-

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Wendell P. Roop is connected with Swarthmore College, Swarthmore, Pa.

Paper by D. Rosenthal and W. D. Mitchell published in September 1950 Research Supplement of THE WELDING JOURNAL, pp. 409-s to 421-s.

ness is reduced the width of the bands does not fall off as much in proportion.

These bands are established in the conditioning phase and their convergence at the apex of the notch establishes there a region of high strain. If, as thickness is reduced, these bands lose width more slowly than has been supposed, then the extent of the conditioning zone is more nearly as great in thin specimens as in thick ones. The way to reduce the importance of the conditioning phase is to increase width.

Kahn's specimens, therefore, and even more Rosenthal's, give greater emphasis to the conditioning phase than the Swarthmore plates.

In summary, it is suggested that:

(*a*) Fracture occurs in two stages; first a conditioning phase, followed by a quicker and more definite advance of the crack.

(*b*) The relative size of the conditioning zone is greater as the specimen is smaller and the notch less acute.

(*c*) When the relative size of the conditioning zone is increased (as in reduction of width on constant thickness) the behavior of the whole specimen comes nearer that of the metal in the conditioning zone, which is relatively unaffected by cold.

(*d*) If, however, increased in thickness on constant width leaves the conditioning zone relatively unchanged in extent; then the rise in transition temperature with thickness has nearly its full value due to the metallurgical cause, without offset of a geometrical nature.

(*e*) The steeper rise in these curves in the present tests, as compared with the Swarthmore plate tests, might indicate that the condition described above in (*d*) actually exists.

When all the implications of the pattern of flow before and during fracture are understood, we will have what is needed to interconvert data taken with different types of specimen. In this pattern the Luders bands have an important place and their dependence on thickness is an important item in the needed information.

Authors' Reply

The authors appreciate Commander Roop's interest in their work. They agree that "the influence on fracture of the geometry of the machined notch must be indirect, exercised by way of events in a preliminary stage of plastic flow." But they see no reason for introducing a new concept of "conditioning zone" to explain their results. It was pointed out by Dr. Zener* that "fracture in metals is initiated by the very act of deformation," and so far this statement has been corroborated by every available information including the one presented in this paper. Therefore, the condition for fracture must be sought in the way the plastic deformation is influenced by the notch geometry, i.e., by the stress-strain relation in the plastic range. Unfortunately the study of this relation in heterogeneous stress fields is still in its infancy. Moreover, even in a homogeneously applied stress field the picture is considerably complicated by the heterogeneity of deformation on a microscopic scale. The best one can hope to do under these circumstances is to extend into the plastic range the study of those geometrical factors which are known to affect the elastic behavior of the specimen. This method is the more justified the less the specimen has been distorted by plastic deformation prior to fracture as is the case of failures of steel below the ductility transition temperature. The present work has been conducted on this very basis, and so far no inconsistency has been found between our results and the available results of direct measurements in the plastic range. Our results are also consistent with the idea that the crack initiates at some depth below the surface of the notch, at a point of presumably the highest triaxiality. Commander Roop wonders why we refer to two biaxialities instead of discussing directly the effect of triaxiality. The reason is that the latter was only inferred from the existence of known biaxialities on the surface, one on the face of the specimen, the other on the cylindrical face of the notch. In this respect the influence of the ratio of the thickness of specimen to radius of notch is one of the important governing factors and it cannot be dismissed as unconcernedly as it has been done by Commander Roop.

Commander Roop refers to his own results to show that the geometrical factors do not determine in a unique way the transition temperature. It is not clear whether the transition temperatures are defined in the same manner in both cases. From the results published by Carpenter and Roop in the April issue of The Welding Journal for 1950, it appears that a considerable absorption of energy has occurred after the inception of the first visible crack. This circumstance suggests that the tests have been conducted above the ductility transition as defined by Vanderbeck and Gensamer, and were concerned with factors promoting the propagation rather than initiation of a crack. Obviously, no simple relation can be expected between these two sets of factors, any more than between the initial geometry of the specimen and the crack propagation.

* "Micromechanism of Fracture," Fracturing of Metals, A.S.M. Publication, 1948.

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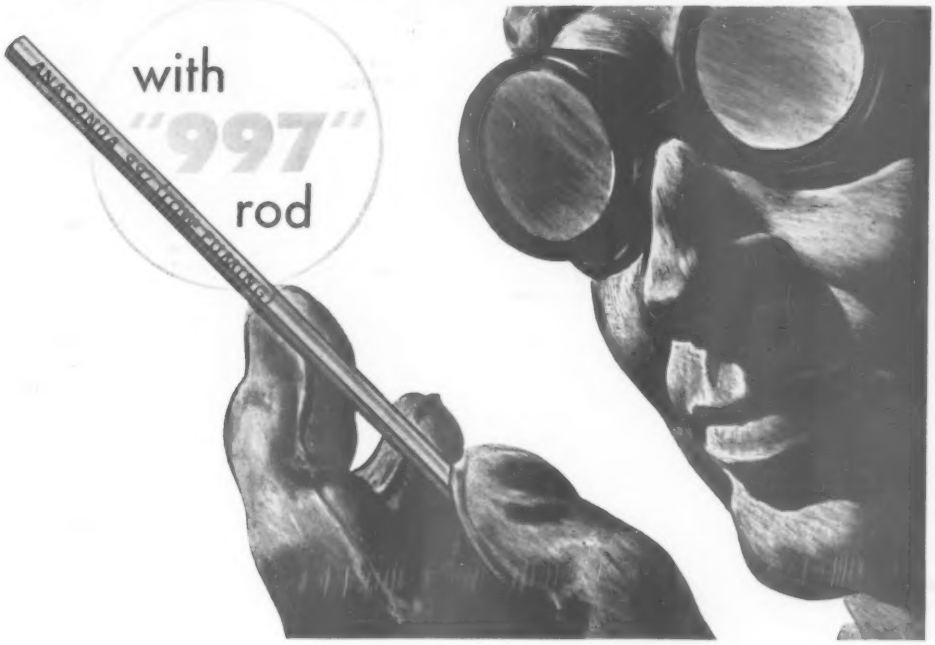

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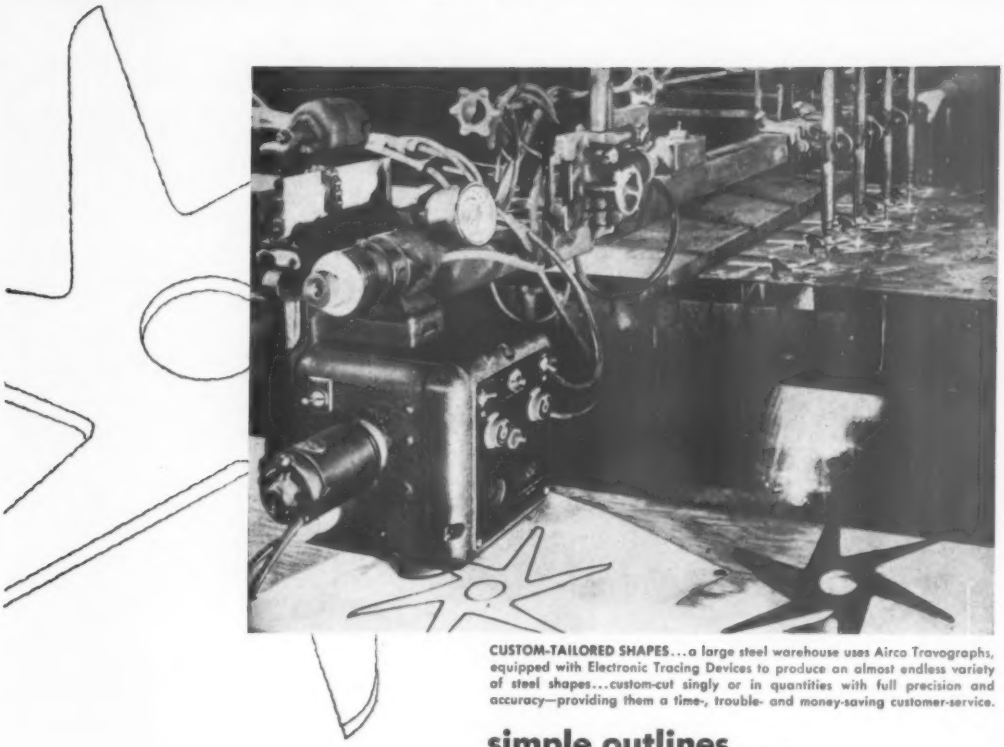

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